The potential impacts of climate change on diseases affecting strawberries and the UK strawberry industry

By

Eman J. Calleja

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University of Warwick, School of Life Sciences

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I dedicate this thesis to my wife,

Michelle

my muse and inspiration

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Declaration

I declare that this thesis and the research that is being contained therein is the sole work of the author, and that none of this work has been presented for another degree. If the author collaborated with colleagues, used or adapted methodologies originally established by fellow academics, this is fully acknowledged in the relevant part of the text.

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Abstract

The impact of climate change on plant disease is an important concern for agriculture. Tools from natural and social science are used in this interdisciplinary study in an innovative way to assess potential impacts on the UK strawberry sector. Records of agricultural statistics and disease incidence covering a 90-year period were analysed to study agricultural change and the past influence of disease on the sector. Future change in potential disease incidence was then modelled for three of the most common diseases by building probabilistic projections for 2020 to 2080 using the UKCP09 scenarios. Using these disease scenarios, data were collected from strawberry growers, through a national survey and case study work in two contrasting areas of strawberry production, covering around 40% of the UK sector.

A number of major outcomes were obtained. The introduction of polytunnels was seen as the most important influence on change in the sector, tripling crop yields and reducing the climatic impact on yield variability. Disease was found to vary spatially and temporally throughout the country, emphasizing the need for development of resistant cultivars, use of pesticides and a change in cultivation methods. Changes in future disease incidence were predicted for all three pathogens, with a high degree of spatial variation. The outcome suggests that the UK Strawberry sector may be vulnerable, not only to the impacts of plant disease, which has affected both the distribution of the sector throughout the UK and profitability of some of the businesses, but especially to pressures arising from other factors such as labour and decreasing profit margins. When coupling these with important policy changes such as the change in the EU Pesticides Directive, a challenging picture emerges for the future of the sector in the UK. Lesson learned from this sector may be applicable to other sectors.

Definitions

Value of home production	Value of the home produce as it was sold by growers.
Nominal value	Refers to the actual value expressed at the time, without being adjusted for inflation.
Average farm-gate price	The price per tonne of the crop. It is the price that growers get on selling their crop, or in other words, the selling price.
Constant pounds	Reflects the currency in real value of a product after the nominal value was adjusted for inflation.
Real value	Refers to the value of a product after it was adjusted for inflation.
Value per planted hectare	The value of earnings obtained per planted hectare. Depends on the planting density and yield per hectare obtained.
Climate Model	As defined by the IPCC in the fourth assessment report: “A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties” (Baede, 2007). A climate model can either be representative of entire earth’s climate system, and known as a Global Climate Model, or else it can represent a sub-global domain, and be known as a Regional Climate Model. The latter also has a higher horizontal resolution (Murphy *et al.*, 2009).
Kriging interpolation	Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. (ArcGis, 2009)
Probabilistic projection	“A projection of future absolute climate that assigns a probability level to different climate outcomes. This

	projection provides an absolute value for the future climate." (Murphy *et al.*, 2009)
Sensitivity analysis	"Sensitivity analysis allows a reviewer to assess the impact that changes in a certain parameter will have on the model's conclusions. It can also help the reviewer determine which parameters are the key drivers of a model's results" (Taylor, 2009).
Adaptation	"Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." Definition in glossary of FAR (IPCC, 2007a)
Anticipatory adaptation	"Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation." Definition in glossary of FAR (IPCC, 2007a)
Autonomous adaptation	"Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation." Definition in glossary of FAR (IPCC, 2007a)
Planned adaptation	"Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state." Definition in glossary of FAR (IPCC, 2007a)
Resilience	"The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change." Definition in glossary of FAR (IPCC, 2007a)

Abbreviations

FERA	Food and Environment Research Agency
PHPS	Plant Health Propagation Scheme
PHSI	Plant Health and Seed Inspectors
MAFF	Ministry of Agriculture, Food and Fisheries
DEFRA	Department for Environment, Food and Rural Affairs
SEERAD	Scottish Executive Environment and Rural Affairs Department
DARDNI	Department of Agriculture and Rural Development of Northern Ireland
CCRI	Countryside and Community Research Institute
SBS survey	Strawberry Black Spot survey
AWB	Agricultural Wages Board
SAWS	Seasonal Agricultural Workers Scheme
GLA	Gangmaster Licensing Authority
IPCC	Intergovernmental Panel on Climate Change
TAR	Third Assessment Report of the Intergovernmental Panel on Climate Change
FAR	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
GCM	Global Climate Model
RCM	Regional Climate Model
UKCP09	United Kingdom Climate Projections

Chapter 1 Introduction

1.1. MOTIVATION FOR THE STUDY

Amongst the various global economic sectors, agriculture has been described as being the most sensitive to climate change and its economic impact (Stern, 2007). Changes in temperature and climatic conditions can influence crop development and growth and, in turn, yields and crop quality. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change predicted increases in the frequency of heavy precipitation events, more frequent and widespread droughts, and a likely increase in the frequency of intense tropical cyclonic activity (Easterling *et al.*, 2007). This will have significant consequences on food and other agro-ecosystem production, over and above the impacts of changes in the mean variables alone (Bates *et al.*, 2008).

To add to these, one cannot discuss the impact of climate change on crops without taking into consideration the effect of change on their diseases. According to a review by Anderson *et. al* (2004), pre-harvest pest and disease damage in the eight most important food and cash crops worldwide accounts for approximately 42% of the attainable crop production, which in the mid-1990s amounted to a production value of over US$300 billion. In the U.S.A alone, crop losses to all plant pathogens total approximately $33 billion per year (Pimentel *et al.*, 2005). The cost to US farmers of fungicides alone is approximately $720 million annually (Pimentel *et al.*, 2005). In the UK, economic loss due to plant pathogens amounts to 8.3% of potential production, or about US$ 2.7 billion per year (Pimentel *et al.*, 2001). These costs and losses could vary from year to year depending on a number of factors, including changes largely related to trade, land use and severe weather events (Anderson *et al.*, 2004). However, when the circumstances are right, plant diseases could develop into severe epidemics that could have devastating impacts on farming communities, lead to strife, and sometimes even social unrest.

In 1943, an estimated 2 million people died during the Great Bengal Famine owing to the high dependence of most of the population on a single crop, rice, which was attacked by the fungus *Cochliobolus miyabeanus* (Strange and Scott, 2005). This episode contrasts to another epidemic, the southern corn leaf blight epidemic of 1970–71 in the USA whereby, although in some areas the crop was completely destroyed by *Cochliobolus heterostrophus,* alternative sources of nutrition were plentiful so no one died of starvation (Strange and Scott, 2005).

The impacts of plant disease are often felt beyond the farm and farming community. In a study by Windels (2000) on the impacts of *Fusarium* head blight in the Northern Great Plains during the 1990s, the worst plant disease to hit the US since the stem rust epidemics of the 1950s, wheat and barley losses caused by scab epidemics were estimated at close to US$3 billion. Apart from severely crippling the wheat and barley industries, the epidemic drove producers to financial ruin and human hardship, and resulted in rural communities dwindling away. In circumstances of financial hardship, producers often give up or retire early, particularly when they are subjected to successive years of net financial losses (Windels, 2000). Some even quit before their assets are gone. Others reduce the number of acres farmed or rent out their land and seek full-time employment. These large scale losses from plant disease, however, can often be followed by a drastic injection of research funds into finding a solution to combating the disease, as has happened with the *Fusarium* head blight epidemics in the USA (Windels, 2000).

To reduce vulnerability to such losses, the USA and Canada have established sophisticated multiple peril crop insurance programmes that help farmers compensate their losses (Ibarra and Skees, 2007). Heavy government subsidies are used (e.g., in the USA farmers pay only about 30 percent of the total costs of the agricultural insurance). Often when these safeguard measures are not available, farmers are forced to give up farming, a decision which, for some farm families, could be personally devastating since it could mean changing a way of life, often being the only life the family has ever known for generations (Windels, 2000). In some areas in the USA, particularly in north-western Minnesota, agencies that deal with the mental strife that comes with farm closures due to disease loss have been set up to help farm families make the transition from life on the land to the job market (Windels, 2000). In lower-income countries, however, Government cannot afford to facilitate income transfers, since a large proportion of the population is often engaged in farming, and the majority of farmers would not have enough income to put a small amount aside to provide for disaster relief. Nevertheless, due to the larger proportion of the population in developing countries being involved in agricultural production or related industries, catastrophic agricultural losses will have a much greater impact on GDP than may occur in developed countries (Ibarra and Skees, 2007).

In view of this, there are increasing calls for research on climate impacts involving plant disease, to focus on assessing the social and economic impacts on the farms themselves and on the wider agricultural sector that is being studied, since this has been largely ignored to date (Barnes *et al.*, 2010). Studies that are in essence interdisciplinary, that link natural science with social science studies are increasingly seen as being essential in developing solutions to adaptation in vulnerable sectors (Rosenzweig and Wilbanks, 2010).

1.2. OBJECTIVES OF THE STUDY

The impact of climate change on plant disease has been receiving increasingly more attention by scientists and research entities in the last ten years, as can be witnessed by the increasing number of disease forecast models that have been published (Booth *et al.*, 2000, Bergot *et al.*, 2004, Salinari *et al.*, 2006, Evans *et al.*, 2008, Turner, 2008). Unfortunately, most climate impact studies involving plant disease fall short of assessing the social and economic impacts that a change in plant disease can have on rural communities (Barnes *et al.*, 2010). In view of this, this study attempts to do just that, by studying how one particular agricultural sector might be affected by, and respond to, any changes in disease incidence, by focusing on the social and economic impacts at farm and regional scales. To do this, tools in natural science and social science will be used in tandem, making this study interdisciplinary in nature.

In view of the funding obtained to carry out this study, part from The Food and Environment Research Agency (FERA) and the rest from the Department of

Environment Food and Rural Affairs (DEFRA), this study will focus on a UK based agricultural sector. After taking into consideration a number of candidate sectors, the UK strawberry sector was chosen as the focus of this study for the following reasons:

- It is the highest grossing horticultural crop[1] in the UK, by itself contributing to almost 13% of the total value of home produced horticultural crops in 2008 (DEFRA, 2010).
- It is grown throughout the UK, and has a history of cultivation spanning at least a century.
- The plant and crop are susceptible to a large number of diseases.
- It is a dynamic sector that makes use of a number of different cultivation methods, which again are affected by different diseases.
- The sector is a known leader of the UK horticultural industry.
- The strawberry sector has been poorly studied, and no climate impact studies have been conducted on either the sector or crop.

The study will essentially consist of a critical interdisciplinary appraisal of the potential impacts of climate change on strawberry diseases and how these could in turn affect the UK strawberry sector and rural land use. In order to achieve this overall aim, the following specific objectives have been set:

- To examine the history of the UK strawberry sector and changes in practices over a specific timeframe.
- To examine the historiography of plant diseases in the UK.
- To examine the recent restructuring of the strawberry sector and analyse the importance and role of plant disease in this.
- To forecast disease prevalence in the UK strawberry sector using various climate change scenarios.
- To examine the response of strawberry growers to the potential impacts of climate change, and assess the adaptability and vulnerability of the sector.

[1] Here referring to both fruit and vegetables, either field grown or under protected cultivation.

1.2.1 Study approach

The first couple of months involved the preparation of a literature review to familiarise oneself with the extent of existing literature on the subject. This was followed by a brief period spent at FERA in Sand Hutton, York, to obtain data relating to disease outbreaks involving the UK strawberry sector in the past. The earliest existing datasets were found to date back to 1920, and a more or less continuous series of records of outbreaks was obtained up till 2009, from various archives and records held by FERA. After the datasets were tabulated and analysed, further data were collected on the UK strawberry sector during the same time period. Agricultural statistics were collected for the strawberry sector from various annual statistical records gathered by the UK government in the past. This was done in order to obtain a picture of how large the sector was throughout the time period covered by the study, and where strawberries were grown throughout the UK. Data on the production methods used were also collected. Links between the disease outbreaks and production methods used were sought and assessed. Historic weather datasets were also obtained from the Metoffice for a number of locations spanning from 1920 to 2009, and links between disease outbreaks and past weather events were assessed.

The collection of data up until this stage (half way through the PhD) had created almost as many questions as answers. To answer some of these questions, particularly on how strawberry farms were set up, and the importance of plant disease in the day-to-day management of the farms, a social science study was conducted through a postal questionnaire targeted at the British strawberry sector. The questionnaire covered various topics, one of which related to climate change and how it might affect growers. Following this, disease forecasting models were built to determine how plant disease incidence will actually change with climate change in Great Britain, under various timeframes and various emission scenarios.

In the final year, the second phase of the social science study was completed through semi-structured interviews with key actors involved in the strawberry sector in two locations in the UK. The two locations were chosen on the basis of their differences in the predicted impacts of climate change on plant diseases. The semi structured interviews were targeted not only at growers, but also at key players in the supply chain. They were used to collect data on the processes driving change in the sector.

The interviews also included a section on climate change and a discussion with the respondents on the potential impacts of climate change on the British strawberry sector and its adaptive potential.

1.2.2 Outline of the thesis

This thesis is structured into 7 chapters. Whilst this first chapter contains the general introduction and the 7th chapter the concluding remarks, the other five chapters (chapters 2-6) largely follow the objectives set in section 1.2. Each of these 5 chapters has its own introduction, literature review, methodology, results and discussion.

The time-frame covered by the study is from 1920 to 2009, to coincide with available disease datasets collected during the first year of the PhD, which are here discussed in chapter 3. As a result, chapter 2 examines agricultural change in the British strawberry sector, over the same period, to enable the study to follow how the strawberry sector has changed in these 90 years. Within it, inferences are made as to how plant disease might have affected these changes. In chapter 4, social science techniques were used to gather further data on the importance of plant disease to the sector, and the processes driving change in the sector in the last two decades. The role of plant disease in possible restructuring of the sector is also assessed.

Following the collection and analysis of data that covered change in the strawberry sector between 1920 and 2009, disease forecasting models were developed in Chapter 5 to assess how disease incidence might change in the next 70 years up till 2080. These are then used in a social science study in chapter 6 that involved representatives from the strawberry sector. In this chapter, the vulnerability and adaptability of the sector to climate change is assessed by taking into consideration the results of the social science study, together with lessons obtained from the past on the influence of plant disease and its importance on the restructuring of the UK strawberry sector.

A conclusion to the thesis is provided in Chapter 7, where an assessment of the outcomes of this study and the methodology used is discussed. This is then followed by suggestions for future work.

Chapter 2 Agricultural change in the British Strawberry sector

2.1. INTRODUCTION

In this chapter, agricultural change in the British strawberry sector is investigated following the collection and analysis of existing agricultural records and statistics compiled by various government entities between 1920 and 2009. Within these records are data regarding the size and distribution of the sector, methods and practices used, and trade data. Change in the sector over this time period will be analysed in terms of its productivity, its geographical range, influence of plant disease and cultivation practices. This chapter will also set the scene for the rest of the study by introducing the British strawberry sector and how it has changed over the 90 years since 1920. Most importantly though, it will attempt to achieve the first specific objective listed in the Introduction to this thesis in section 1.2.

The chapter starts with a literature review about agricultural change in the UK, then about world strawberry production, and where the UK strawberry sector lies in respect to that. This is then followed by a description of the methodology used, and then results and a separate discussion. A summary then concludes the chapter.

2.1.1 Agricultural change in the UK

Like most other sectors in UK agriculture, the strawberry sector has gone through a period of major structural change, driven by the need to adapt to market trends and other driving forces present at that particular time. This has led to a change in the structure, size, shape, location and strength of the industry. However, in order to understand all these, one has to first understand how UK agriculture changed in the last century.

It is widely accepted that UK agriculture has gone through two periods of major structural change. The first period, known as the 'productivist' phase (Ilbery and Watts, 2003), started just after the Second World War and lasted through the 1960s and 1970s. It was driven by strong government support and then later by EU aid, the latter through the Common Agricultural Policy (CAP). This led to the modernisation and industrialisation of agriculture with fewer, larger and more capital intensive farms, being more fragmented spatially across Great Britain (Ilbery, 1988). Modernisation in agriculture was fuelled by three key processes, which were occurring throughout the industrialised world (Ilbery and Maye, 2010). The first was intensification, where the yield per hectare increased through the use of mechanisation in farming, wider use of chemicals (such as pesticides, fungicides and fertilizers) and the adoption of disease-resistant varieties. The second process was specialisation, whereby farms chose to stop farming unprofitable crops in favour of maximizing the production of more profitable crops, thus gradually obtaining their income from fewer products. The third and final process was concentration, where production was becoming increasingly concentrated on fewer farms in specific regions, aided by, as Harvey (1963) suggested, three specific processes: agglomeration, cumulative change and diminishing returns. Others have also suggested that farmers in certain areas responded differently to national agricultural process, resulting in uneven spatial development (Munton *et al.*, 1988). This was heightened by the development of enterprises in areas in which they have a traditional association; this helps to explain the segregation of British arable and livestock farming into the arable east and pastoral west (Ilbery, 1988). As a result of intensification and specialization, British farming gradually became detached from its consumers and the rural economy in general and, by doing so, the link between 'product' and 'place' was broken (Ilbery and Maye, 2010). The supply chains became longer with more intermediaries, with more of the product going to supermarkets.

The second phase of agricultural restructuring started in the mid to late 1980s. Sometimes referred to as post-productivism (Ilbery and Watts, 2003), this arose due to a number of difficulties associated with the industrialisation of agriculture, such as environmental degradation, a large number of family farms going out of business, and a number of food scares and animal health issues such as BSE, foot and mouth disease, and *E. coli*. By the turn of the millennium, and after yet another animal welfare crisis, the UK government commissioned a report into the foot and mouth disease outbreak. The report, published in 2002, also known as the ‘Curry Report’, criticised UK food supply networks, suggesting that food production had become too industrialised and intensive, and that the producers of food had become ‘disconnected’ from food consumers, and vice-versa. The report also suggested that multiple retailers (or supermarket chains) had become too powerful and were now influencing not only what producers grow and how they grow it, but also what food consumers buy and eat (Holloway, 2008). All of these factors led to a resurgence of demand for a more extensive agriculture that is sustainable and environmentally friendly. This post-productivist phase of agriculture has the added benefit of linking producers to consumers by shortening the food supply chain (Ilbery and Watts, 2003). In turn, these developments have been encouraged by a change in EU policy towards agriculture and by expansion of the ‘second pillar’ of CAP (Lowe *et al.*, 2002).

2.1.2 World strawberry production

Although the strawberry has been consumed as a wild crop since Roman times, the first reference to strawberry cultivation in Europe appears only in the 1300s, and this then referred to the wild species, *Fragaria vesca* (Darrow, 1966). The cultivated strawberry only appeared in the mid-eighteenth century when naturally formed hybrids of *F. chiloensis* and *F. virginiana* started to appear in Brittany (Darrow, 1966). Another half a century had to pass before the first strawberry breeds originated in England in 1817. They were called Downtown and Elton and were noted for their large fruit, vigour and hardiness (Hancock, 1999).

By the end of the 20th century, strawberries were grown commercially in a broad range of climates including subtropical, temperate, grassland, Mediterranean, and Taiga, however most of the production was limited to the Northern hemisphere (Hancock, 1999). By 2008, the global production of strawberries was of almost 4.1 million tons, making it the 76th major crop worldwide in terms of output (FAOSTAT, 2008). In the UK however it was the 24th major crop (FAOSTAT, 2008), and the second most produced fruit in the country. In terms of value however, it was the most important horticultural crop, on its own contributing to almost 13% of the total value of home produced horticultural crop in 2008 (DEFRA, 2010).

Globally, the three biggest producers of strawberries in 2008 were the USA, Spain and Turkey (Table 2-1). The biggest exporter of fresh strawberries in 2007 was Spain, which exported just over 70% of its fresh strawberry production (FAOSTAT, 2008). With regards to imports, the UK is one of the leading countries, ranking as the 5th country in terms of quantity of imported strawberries (FAOSTAT, 2008).

Table 2-1 Output of strawberries by the 20 major producing countries (FAOSTAT, 2008)

Rank	**Country**	**Production (tonnes)**
1	United States of America	1,148,530
2	Spain	263,900
3	Turkey	261,078
4	Mexico	207,485
5	Korea, Republic of	203,227
6	Poland	200,723
7	Egypt	200,254
8	Japan	193,000
9	Italy	155,583
10	Germany	150,854
11	Russian Federation	145,000
12	Morocco	130,000
13	United Kingdom	87,200
14	Ukraine	52,900
15	Belarus	50,400
16	Colombia	43,920
17	France	43,541
18	Netherlands	41,000
19	Belgium	40,000
20	Chile	40,000

2.1.3 The UK strawberry industry

Strawberry cultivation in Great Britain expanded very rapidly towards the end of the 19th Century and by 1924, after a short drop in production during the First World War, reached its peak at 13,000Ha (Ellis, 1970). After a gradual decrease up till the 1980s, the British strawberry industry expanded rapidly again and by the end of the 1980s represented a substantial component of UK fruit production (Beech and Simpson, 1989). Output increased through the introduction of new varieties and growing systems which improved productivity and fruit quality (Beech and Simpson, 1989). These, together with emphasis on quality control, and involvement of the supermarket chains in the marketing process have helped to increase sales of fresh fruit. The increasing availability of imported fruits and greater production from UK-grown everbearing strawberries has spread the season from March to October instead of just a six-to-eight week period in June and July (Beech and Simpson, 1989).

A wide array of protected systems is used in the UK to maximize the harvest period. By the end of the 1990s these consisted of floating mulches, low-tunnels (polythene cloches), portable high tunnels (French and Spanish tunnels), and glasshouses (Hancock, 1999). Matted rows in the open were mostly popular on pick-your-own farms, but runnerless culture under protection dominated commercial production (Hancock, 1999).

The output value in the late 1980s was £61 million (Beech and Simpson, 1989). By 2008, the turnover for the UK Strawberry Industry had gone up to £213m (DEFRA, 2010). The quantity of home production in the UK was 104,900 tonnes in 2008, grown over an area of 4879 Ha (DEFRA, 2010) which was almost three times lower than the area under cultivation in 1924. Of these, almost 25% was grown in the south east of the country which includes Kent and East Sussex (DEFRA, 2010).

2.2. METHODOLOGY

Various sources of agricultural statistics were collected and analysed to study agricultural change in the British strawberry sector between 1920 and 2009. As mentioned in the introductory chapter, data for these years were collected so as to coincide with the period for which disease datasets were available.

2.2.1 Sources of data

Almost all of the existing statistical data on strawberry production for the UK or Great Britain used for this study were obtained from grey literature[2]. These datasets originated from various sources of agricultural statistics collected by a number of government departments in the past, most usually through the annual June survey data collection exercises. The data are often fragmented and were collected by different sources throughout the period covered by this study (1920-2009). Administrative changes at both government and departmental levels in the UK and individual counties, added to the further complexity of the data, such that whereas data were collected by the Scottish, English or Northern Irish departments of Agriculture in the past, and presented at a country level, it is now presented at a combined UK level. Some of the data were only collected on an occasional basis and exist only for a few years or decades. Considering the length of the period covered, in only a few cases could a continuous time series be built up for a dataset that would cover the whole study period from 1920-2009.

Table 2-2 Sources of statistical data used in the analysis

Title	Authors
Agricultural statistics - Scotland	Great Britain. Department of Agriculture for Scotland.
Agricultural statistics - England	Great Britain. Ministry of Agriculture, Fisheries and Food
Agricultural statistics - United Kingdom	Great Britain. Ministry of Agriculture, Fisheries and Food

[2] Data for Northern Ireland were not available for most of the datasets, thus the reference to the British strawberry sector in this Chapter.

Title	Authors
MAFF statistics. Agricultural and horticultural census: United Kingdom and England	Great Britain. Ministry of Agriculture, Fisheries and Food
Basic horticultural statistics for the United Kingdom	Department for Environment, Food and Rural Affairs (DEFRA)
Pesticide usage survey reports	MAFF/FERA/DEFRA
Unpublished strawberry statistics dataset	Obtained directly from DEFRA, SEERAD and DARDNI

Over 20 different datasets were built from the sources of agricultural statistics referred to in Table 2-2. These were used either as raw data or else transformed to create other datasets such as yield. Units were harmonised to be consistent throughout the time series, i.e. earlier datasets that used acres and tons were converted to hectares and tonnes for consistency.

Table 2-3 Datasets collected from the agricultural statistics referred to in Table 2-2

Dataset	Time covered	Complete/ Fragmented
Area under strawberry cultivation (crop area) for the UK (Hectares)	1924-2010	Complete
Area under strawberry cultivation (crop area) for England and Wales (Hectares)	1920-2009	Complete
Area under strawberry cultivation (crop area) for Scotland (Hectares)	1920-2009	Complete
Area under strawberry cultivation (crop area) for Northern Ireland (Hectares)	1924-2009	Complete
Quantity of strawberries produced for UK (Tonnes)	1942-2009	Continuous
Quantity of strawberries produced for England and Wales (Tonnes)	1923-2009	Fragmented
Quantity of strawberries produced for Scotland (Tonnes)	1925-2009	Fragmented
Quantity of strawberries produced for Northern	1942-1979	Continuous

Dataset	**Time covered**	**Complete/ Fragmented**
Ireland (Tonnes)		
Value of home production marketed in the UK (Sterling)	1948-2009	Continuous
Monthly marketing patterns for England and Wales	1960-2009	Fragmented
Imports - quantity for the calendar year in the UK (tonnes)	1971-2009	Continuous
Imports - value for the calendar year in the UK (Sterling)	1971-2009	Continuous
Exports and re-exports - quantity for the calendar year from the UK (tonnes)	1971-2009	Continuous
Exports and re-exports - value for the calendar year from the UK (Sterling)	1975-2009	Continuous
Strawberry cultivars used by the sector	1948-2009	Fragmented
Proportion of strawberry cultivation under protection	1973-2009	Fragmented
Area of strawberries grown in each county in Great Britain	1920-2009	Almost continuous
Spray area of fungicide used (Hectares)	1965-2006	Fragmented
Spray area or three main fungicides used (Hectares)	1965-2006	Fragmented
Quantity of three main fungicides used (kgs)	1990-2006	Fragmented
Percentage of crop area not treated with pesticides	1965-2006	Fragmented
No of years plants are kept before they are replaced	1971-2006	Fragmented
Number of holdings involved in strawberry cultivation in Great Britain	1980-2009	Fragmented

2.2.2 Analysis of data

Following the collation of the datasets, the data were arranged into time-series in order to assess the change in a variable over time. In some cases data were re-organised spatially to assess the geographic variation of a specific variable. In the latter case, the data were plotted using ESRI® ArcMap^{TM} 9.2. In various other cases, the primary data were transformed into secondary data to obtain more information out of a time-series. One of the transformations involved adjusting values of strawberries for inflation. In this case, the values obtained through the agricultural statistics were adjusted for inflation in order to reflect the “real value” of the crop in “constant pounds” sterling, thus enabling the assessment of the income obtained by growers along a time series. The transformation was undertaken using the Bank of England’s Inflation Calculator (Bank of England, 2010) which uses the composite price index published by the Office for National Statistics (O’Donoghue *et al.*, 2004), to calculate the change in cost of a commodity over time.

Various statistical methods were used to test the data including:

- Two-sample unpaired t-tests to assess whether the yield of two groups was significantly different,
- correlation analysis to test a linear correlation between two variables,
- simple linear regression with groups, to test whether two slopes or trends are significantly different from each other,
- 5-year moving variance, to study the change in year to year variation of a variable.

The statistical tests were conducted using GenStat® 12th edition.

A number of graphical methods were used to display the results including tables, scatter plots, vertical bar charts, stacked bar charts and clustered column charts.

2.3. RESULTS

In this section three broad themes will be discussed. These include the following:

I. **Changing nature of the British strawberry sector**. The change in area and size of the sector is first analysed, followed by an analysis of the geography of strawberry cultivation and how the core strawberry areas have shifted throughout Great Britain over time. This is then followed by the analysis of the change in yield and productivity of the sector with time.

II. **The changing value of British Strawberries**. The change in value of the sector with time is analysed, including the value and quantity of imports and how they relate to the British grown crop.

III. **The change in production methods**. Production methods and cultivation practices used during the 90 years covered by the study is discussed. These include the change in use of cultivars, use of protection, and use of plant protection products. Analysis of these and assumptions as to their influence on yield and productivity of the sector are also made.

2.3.1 The changing nature of the British strawberry sector

2.3.1.1. Change in crop area

The area used for strawberry cultivation (crop area) in Great Britain has changed significantly since 1920. It reached its peak in 1924 at almost 13,000 ha (Figure 2-1). It then decreased almost threefold during the Second World War. Just after the war, strawberry production increased again, the area doubling in size to over 8,000 ha. Between 1950 and 1980, the total area remained stable between 6,000 and 8,000 ha. The last major change has occurred since the early-1980s, when the crop area decreased gradually to reach the lowest level since records began at the turn of the century (1900). This decrease stabilised to a crop area of around 4200 ha in Great Britain by 2009.

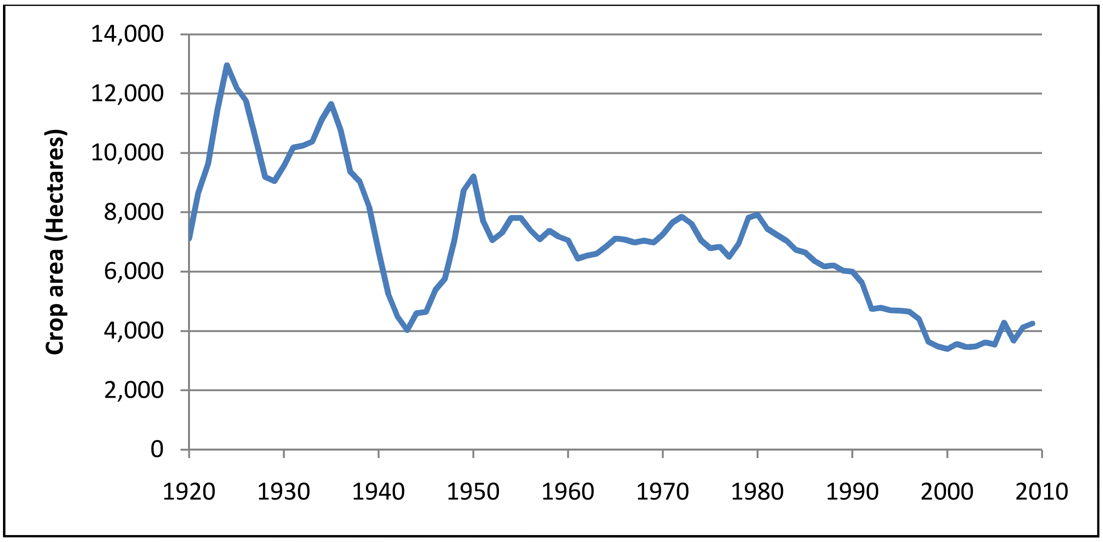


Figure 2-1 Change in crop area of strawberries produced in Great Britain (England, Scotland & Wales), 1920-2009.

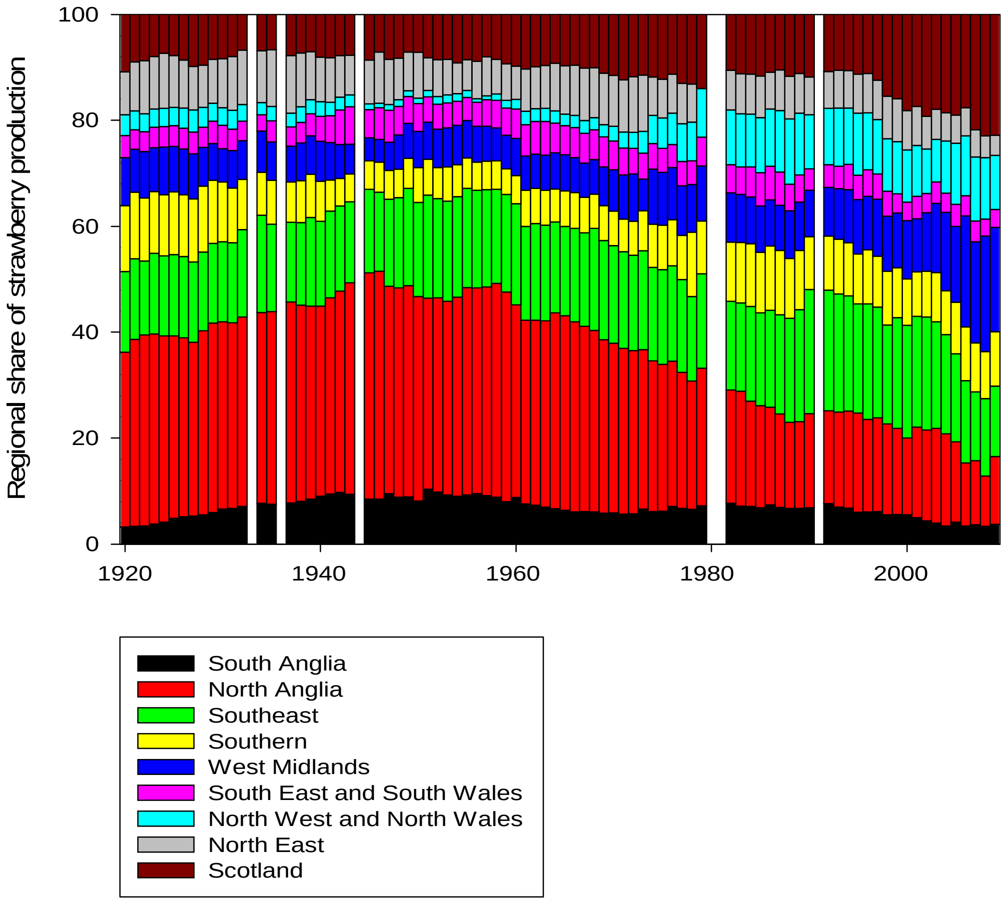


Figure 2-2 100 % stacked chart showing the changing regional share of strawberry production in Great Britain, 1920-2009. The share was taken as a percentage of the total area cultivated in Great Britain. Empty gaps represent missing data.

On dividing the data into different regions across Great Britain (Figure 2-2), it can be seen that the main centres of strawberry cultivation have shifted over time. Production in North Anglia (refer to Figure 2-2) was dominant until the 1970s, contributing one-third of the total crop area in Great Britain. Since then, production has shifted to other regions including Scotland, North West & North Wales, and the West Midlands.

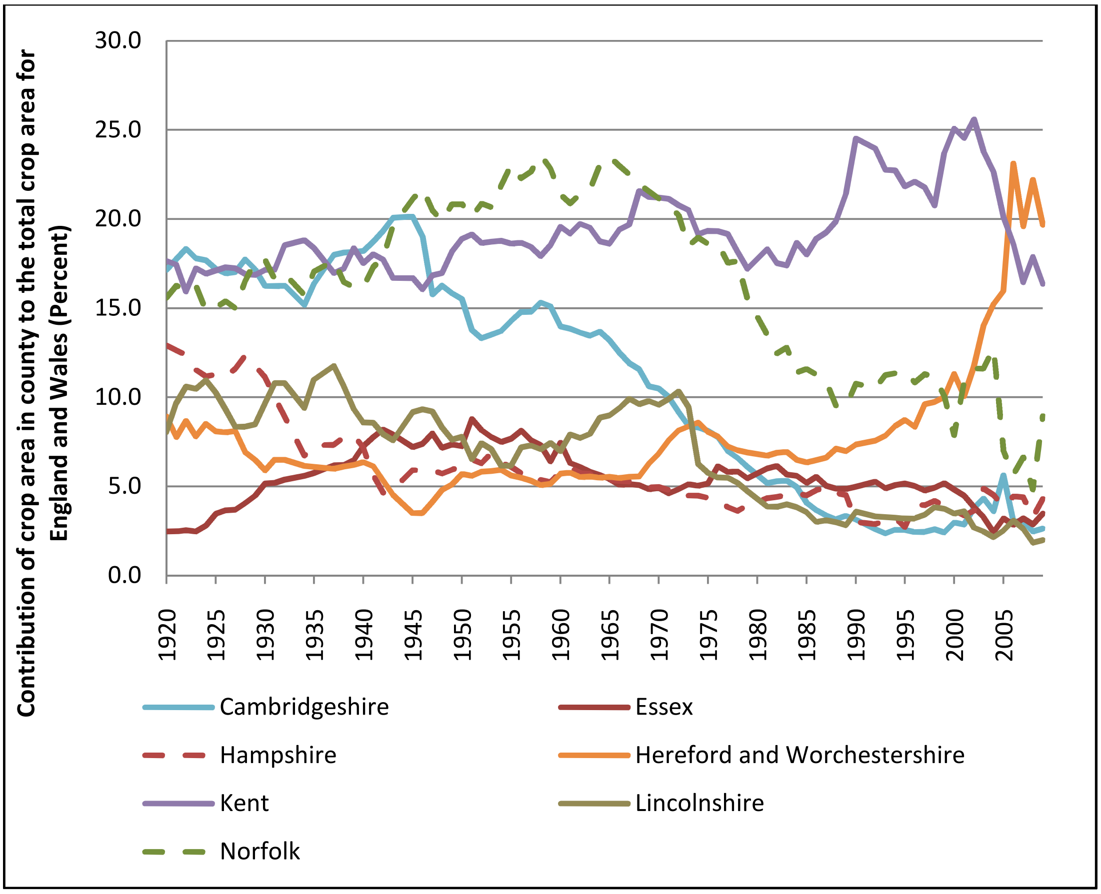


Figure 2-3 Contribution of crop area in selected counties to the total area of strawberries in England and Wales.

On analysing the contribution of the most important counties to the national crop area, the focus of the strawberry sector shifted within the country. This happened in both England (Figure 2-3) and Scotland (Figure 2-4). In England, the counties of Cambridgeshire, Norfolk and Lincolnshire (North Anglia) together contributed to half of the total crop area for England and Wales by 1946. Thereafter, strawberry cultivation in Cambridgeshire went into decline. The same happened in Lincolnshire, whereby the sector went into decline slightly later, at the end of the 1960s. The sector in Norfolk thrived for another thirty years, even dominating the sector between 1945 and 1966; however, it also went into decline thereafter. These three counties account for the decline of the sector in the northern part of East Anglia. On the other hand, the sector in Kent dominated the strawberry industry in the 1980s and 1990s, only to be overtaken recently by a rapid expansion of the sector in Herefordshire and Worcestershire.

In Scotland, Lanarkshire was the most important county for the Scottish strawberry sector up until the Second World War. This changed subsequently, with Perth (the Perthshire and Blairgowrie area) and Forfar (the Forfar and Angus area) taking up production. As a result, the Scottish strawberry sector gradually moved to the east of the country, and nowadays is virtually absent from the central and western counties of Scotland.

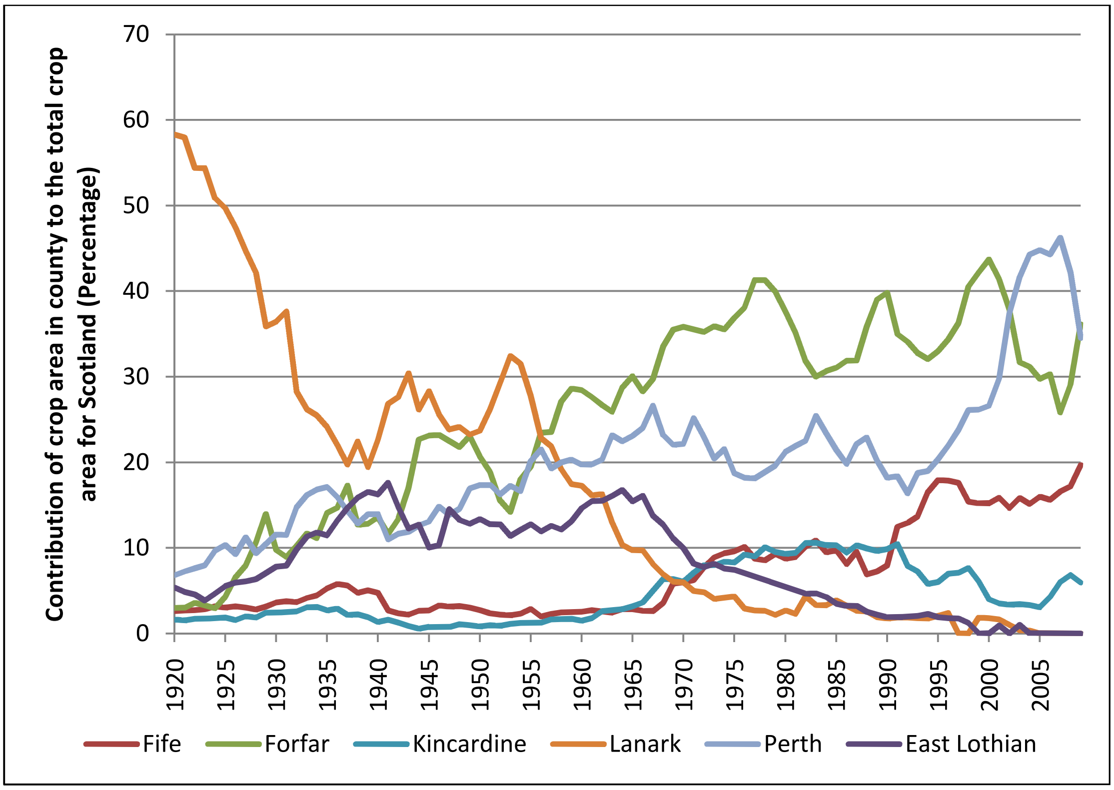


Figure 2-4 *Contribution of crop area in selected Scottish counties to the total area of strawberries in Scotland*

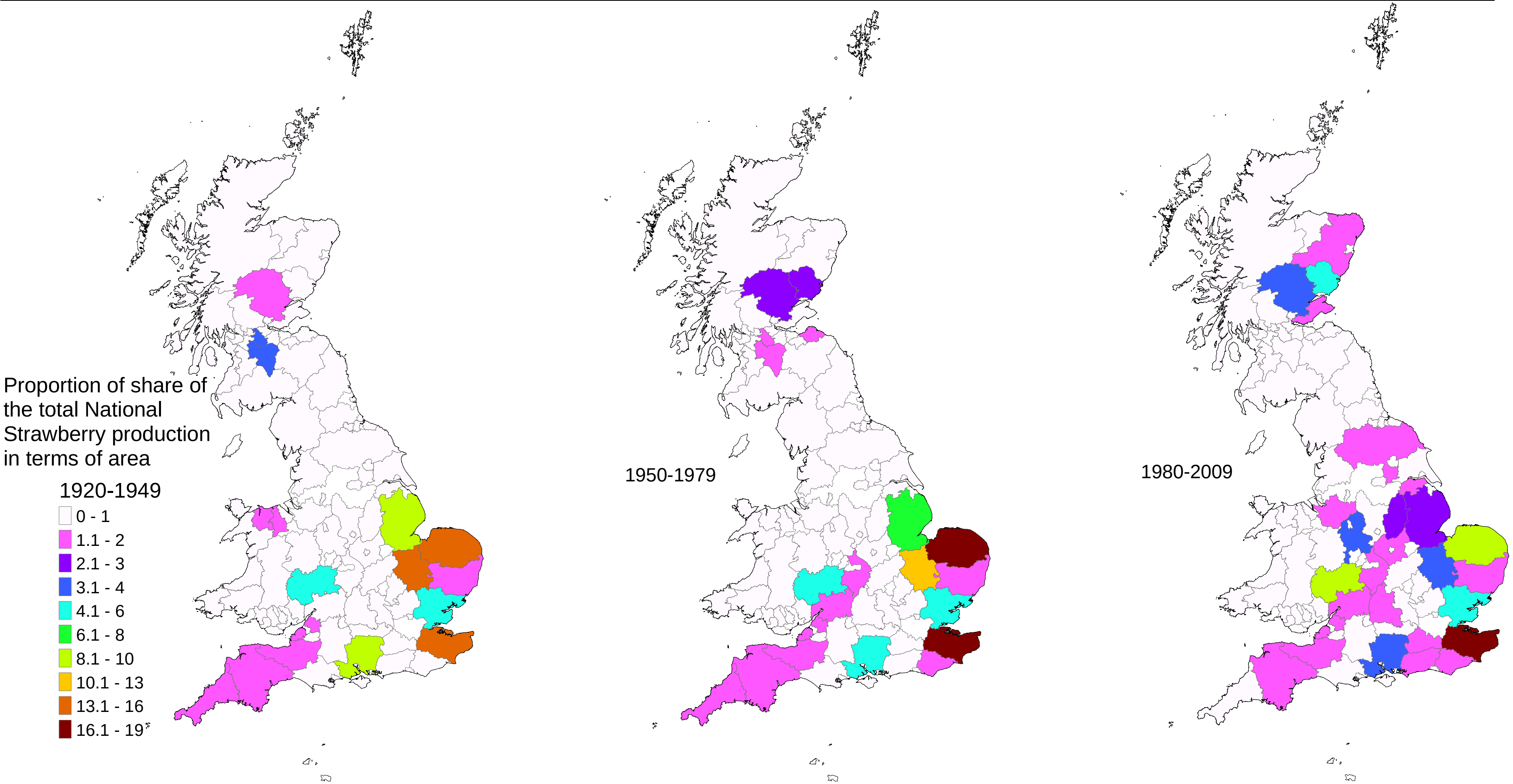


Figure 2-5 Changing geographical distribution of strawberry production in Great Britain, 1920-2009. Legend with proportions on the left is applicable to all three maps.

Whilst the sector was shifting its centre of production from 1980 to 2009, a change in farm size was also observed. In England the average size of strawberry farm increased from 2.2 ha per farm in 1981 to 3.0 ha in 2006, resulting in a 36% increase in size (Figure 2-6). The increase in size of a strawberry farm in Scotland was more drastic, with the average increasing from 2.1 ha in 1982 to 7.1 ha in 2009, a 245% increase in size (Figure 2-7). The increase in size of strawberry farm was more pronounced in those counties that experienced an increase in their contribution to the total national crop area for the strawberry sector, possibly suggesting a link between the farm size and increase in total crop area within a county. These include Kent, Herefordshire and Worcestershire, and more recently Staffordshire in England, and Angus, Perthshire and Fife in Scotland.

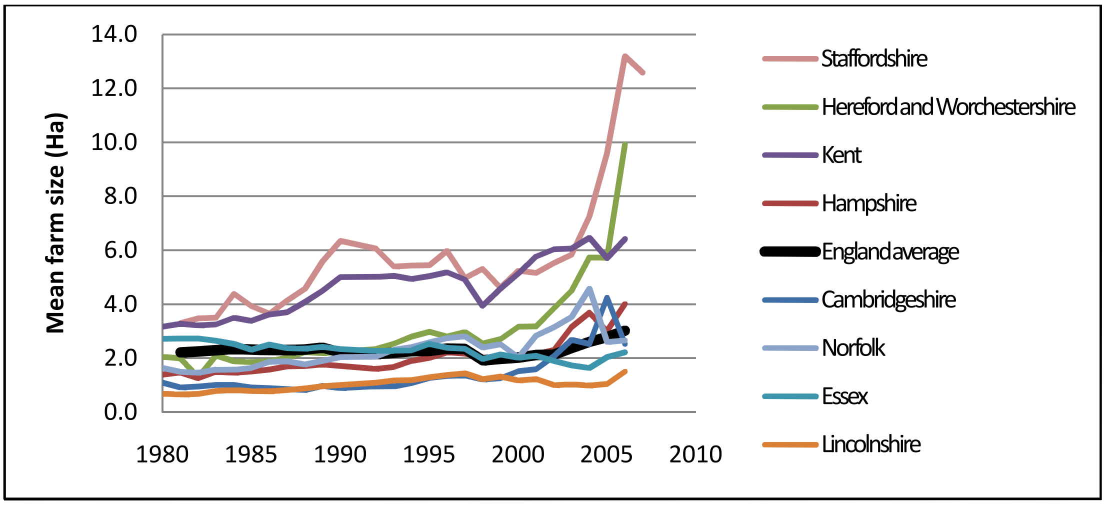


Figure 2-6 Change in average size of strawberry holdings in England between 1980 and 2007

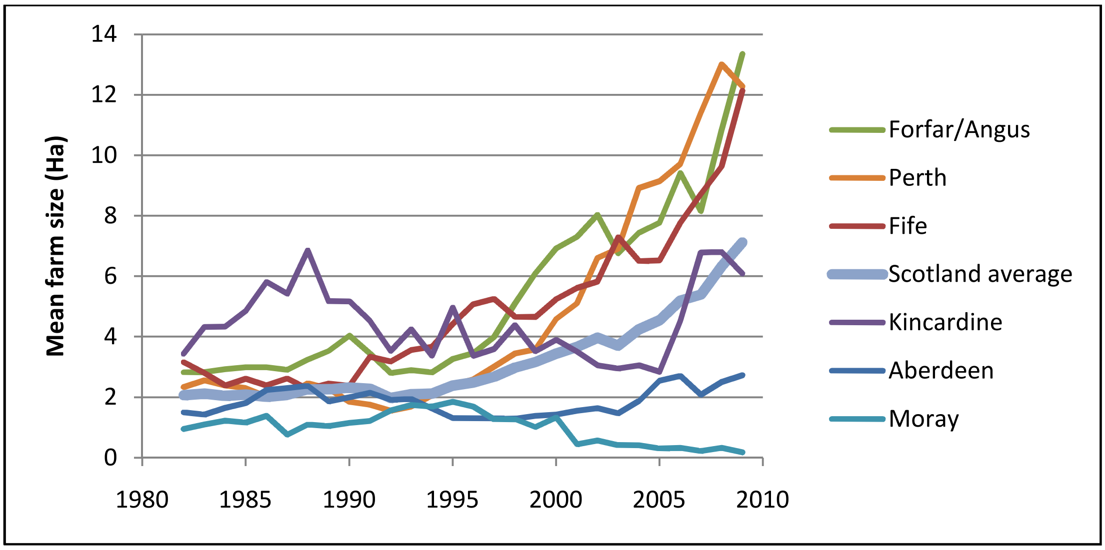


Figure 2-7 Change in average size of strawberry holdings in Scotland between 1982 and 2009

2.3.1.2. Change in output and yield

Whilst the area has gradually decreased to almost a third of the coverage recorded in 1924, the output of strawberry production has more than doubled since 1925 (Figure 2-8).

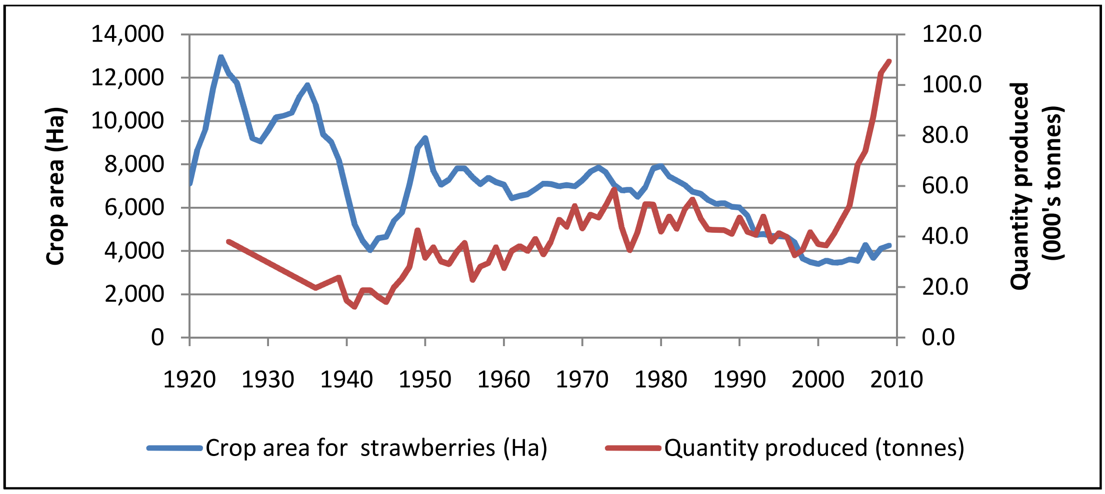


Figure 2-8 Change in crop area and output of strawberries produced in Great Britain (England, Scotland & Wales), 1920-2009. Data for output (quantity) between 1926-1935 were missing

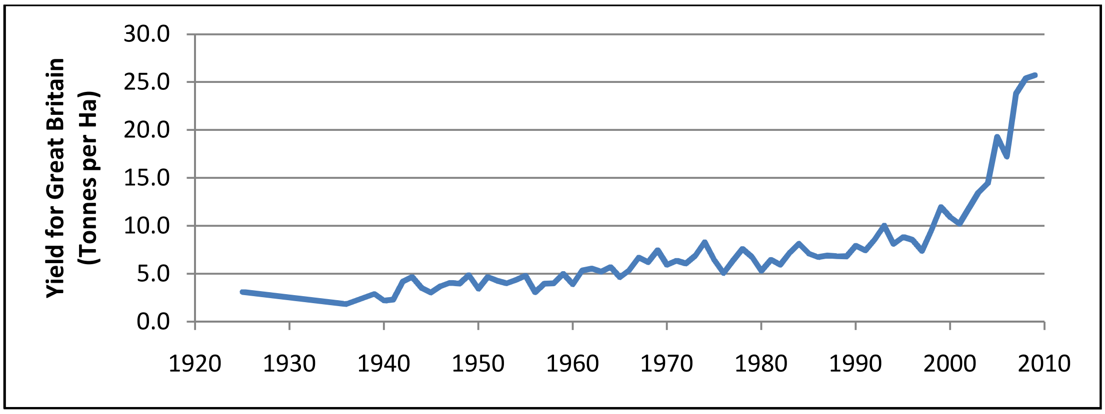


Figure 2-9 Changes in strawberry yield in Great Britain, 1920-2009 (tonnes per ha).

The yield per unit area has increased 6-fold over the same period (Figure 2-9). Initially, the yield was below 5 tonne per ha in the 1920s, gradually increasing until the late-1990s, where a rapid growth in yield was observed, reaching 25 tonnes of strawberries per hectare by 2009. Growth in the yield per unit area seemed to occur in two phases. The first phase was from 1940-1996[3], with only a mild increase in yield and a slope of 0.0953 (r=0.894). The second phase started in 1997 till 2009,

[3] Data for 1920-1939 was omitted due to the lack of data available for output of strawberries.

and had a faster rate of increase in yield and a slope of 1.518 (r=0.945). The difference in the slope of the two phases was tested using a simple linear regression with groups using GenStat® (the two groups being the two phases). The regression obtained an F-value of < 0.001 suggesting that the two phases could be considered as distinct from each other.

The difference in average strawberry yields in England and Scotland was statistically significant in the first phase (Figure 2-10), from 1940-1996, with a t-value of < 0.001[4], and a slightly faster rate of growth in English farms ($slope^{England}$=0.102; $slope^{Scotland}$=0.0671). In the second phase, from 1997-2009, the difference in yields was not statistically significant (t-value = 0.633[5]) even though the rate of growth in English farms was slightly higher than that of Scottish farms ($slope^{England}$=1.63; $slope^{Scotland}$=1.13)[6].

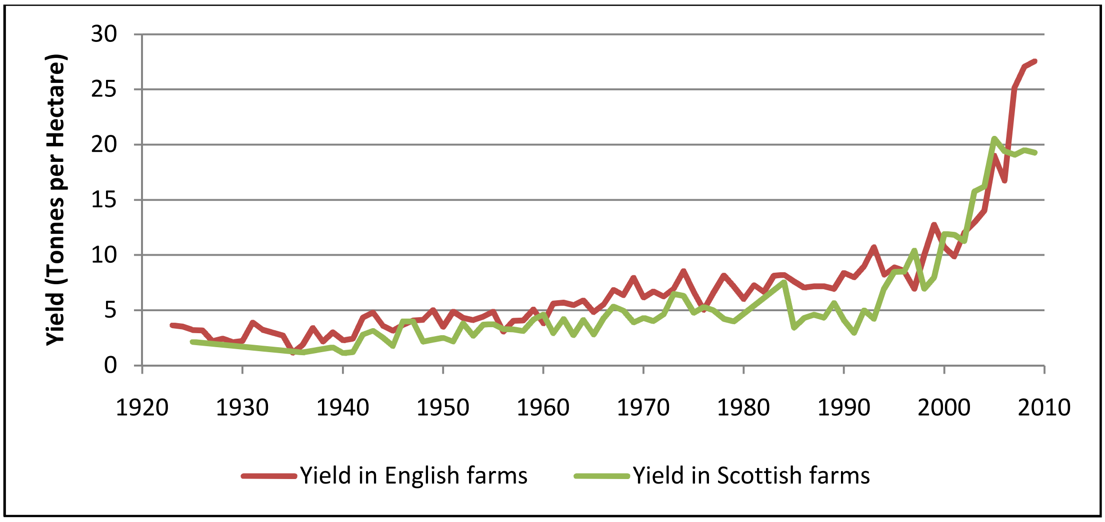


Figure 2-10 Strawberry yields obtained on English and Scottish farms (tonnes per ha).

This is further corroborated in Figure 2-11, which shows a distinct difference between the slope of the first and second phases. In the first phase, the yield obtained on English farms was higher than that obtained on Scottish farms by around 53.4% on average (median = 42.7%) and a variance of 17.7. In the second phase (1997-2009), the difference in yield had abruptly decreased to a mean of +8.6% in favour of English farms, with a variance of 9.3.

[4] A two-sample unpaired t-test was performed on the yields of the two countries.
[5] Same two-sample unpaired t-test was performed
[6] Whilst in the first phase English farms had an advantage over Scottish farms having obtained higher yields, this changed in the second phase as the yields were found not to be significantly different. This could suggest that something happened in the second phase that bridged the gap between English and Scottish farms.

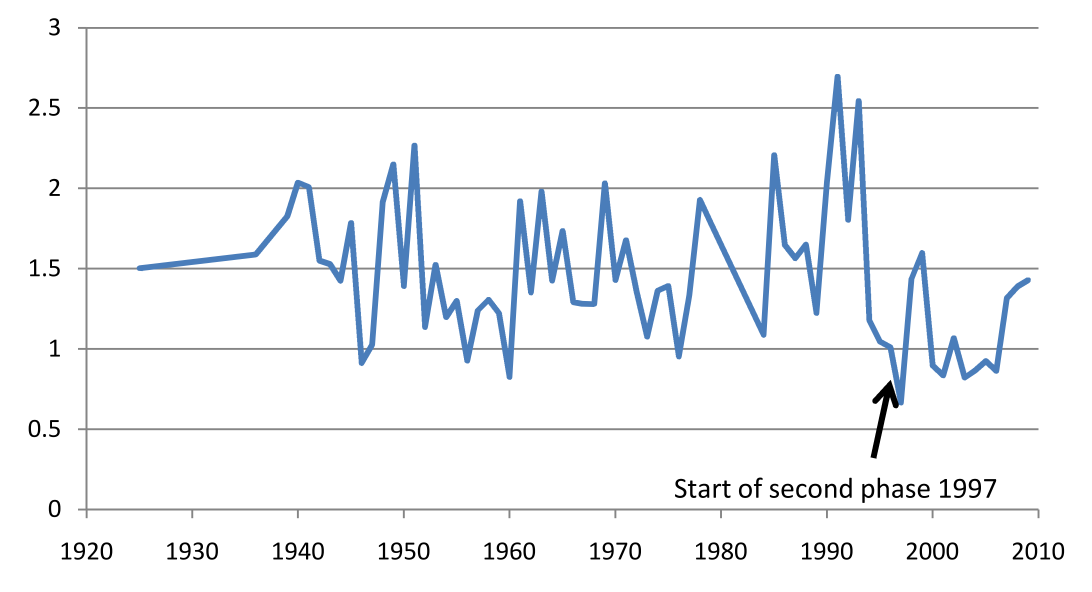


Figure 2-11 Ratio of yields obtained in English to Scottish strawberry farms (obtained by dividing the English yield by the Scottish yield). A value of 1 means that the yields are equal to each other.

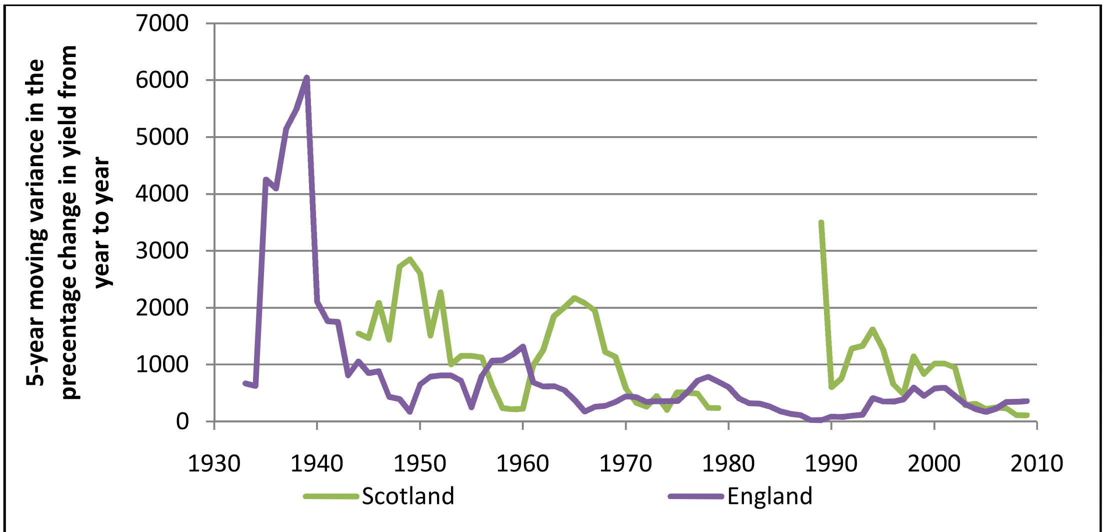


Figure 2-12 The rate of yearly variation in strawberry yield for the two countries. A point represents the variance of the five years preceding it.

The yields have also fluctuated dramatically from year to year. These fluctuations have been decreasing over recent years to a mean of around ±10% for English farms in 2009, and ±18% for Scottish farms. This trend can be seen better in Figure 2-12 which shows the 5-year moving variance[7] in the percentage change in yield from

[7] The five year moving variance is a statistical tool to study the change in year to year variation. In this case the variable is the yield, and the variance that is being measured represents the year to year change in yield. The 5 year moving average smoothens out the extremes, and the outcome gives an

year to year for both countries. This decrease in year to year variability could be of significance since unpredictable yields could be negative to a sector, and is evidence of a strong influence of weather and plant disease affecting the annual yield. However, if the year to year variation decreases, one reason could be that growers have introduced production methods that enable them to have greater control on the growth and output of their crops. This would result in more sustainable and constant yields.

2.3.2 The changing value of British Strawberries

2.3.2.1. Change in farm-gate value of crop

The overall nominal value (see definitions) of home production for the British strawberry sector has increased drastically since the 1920s (Figure 2-13). In 1925, it was worth £1.75m. By 2009, it was worth £231m[8].

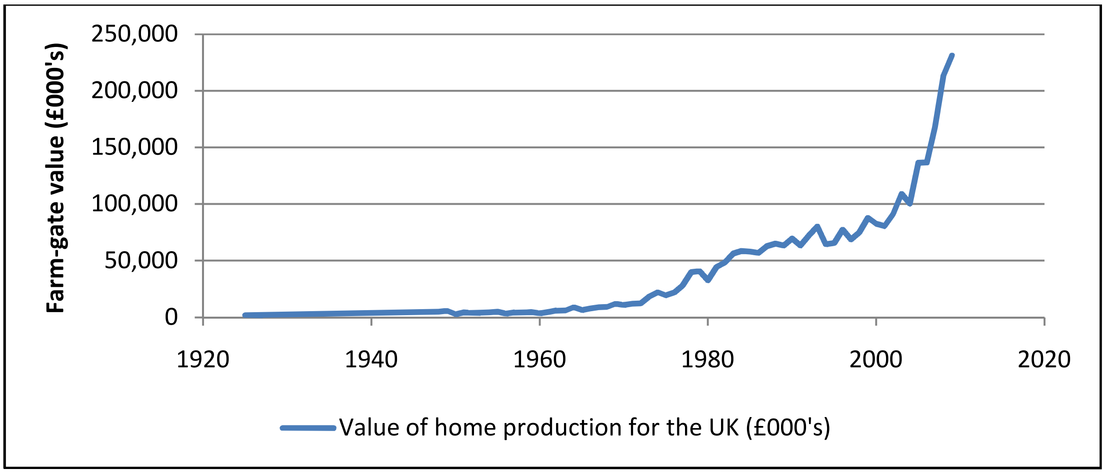


Figure 2-13 Nominal value of home production for the UK strawberry sector. These data were only available at the UK level.

The average farm-gate price of the crop in nominal £s per tonnes also increased, particularly in the 1970s and 1980s, until it reached a peak in 2000. Since then, it has gradually decreased, to around £2000 per tonne (Figure 2-14). This nominal value was adjusted for inflation by using the Bank of England's inflation calculator (Bank of England, 2010) to determine the real value of the crop in 'constant pounds' sterling (see definition). This is depicted by the red line in Figure 2-14. The real

indication of how the yield is changing from one year to the next. Thus a scatter plot with a line close to the x-axis denotes little change in yield from year to year.

[8] These figures refer to the nominal values which have not been adjusted for inflation.

value of strawberries remained relatively stable between 1950 and 2005, at between 2,000 to 3,000 'constant pounds' per tonne. The mean real value since 1920 was £2,663.8 with a standard deviation of £407.7 (median = £2,691.3). In the last 5 years, the real value of the crop has reached its lowest level, dipping below £2,000 per tonne.

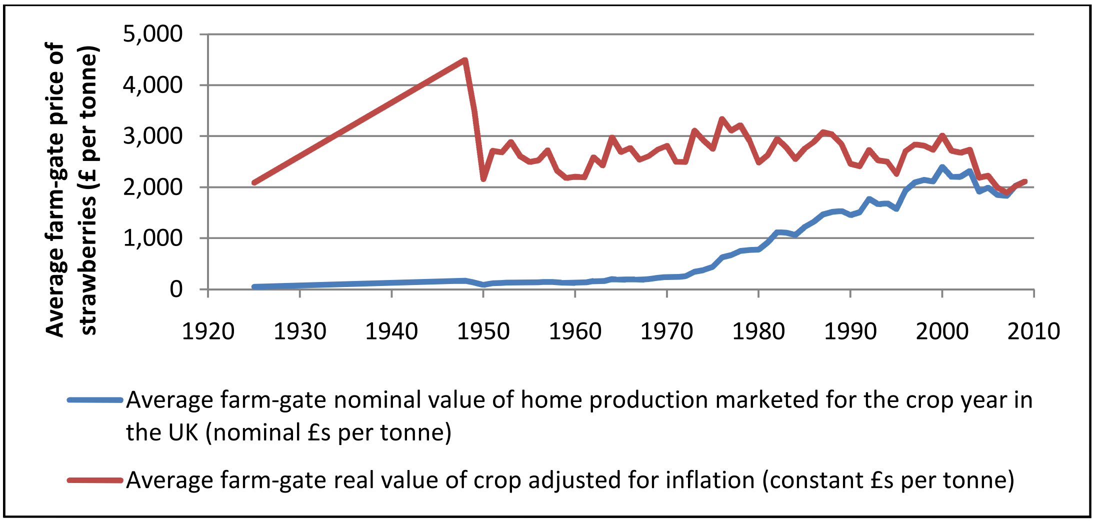


Figure 2-14 Average farm-gate price of home production marketed for the crop year in the UK in £ per tonne. These data are available only at the UK level. Data between 1926 and 1947 were missing.

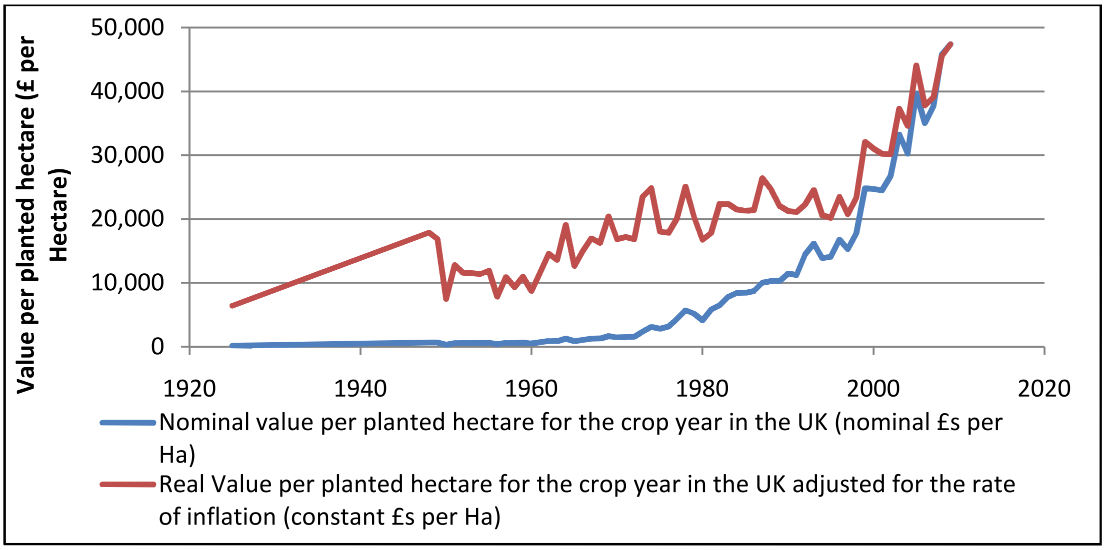


Figure 2-15 Value per planted hectare for the crop year in the UK. This was obtained by dividing the total turnover by the total crop area.

The nominal value per planted hectare also increased particularly since the 1980s, from £141 per hectare in 1925 to £47,400 per hectare in 2009 (Figure 2-15). When this was adjusted for inflation to reflect the real value per planted hectare (red line in

Figure 2-15), the real value of total crop per planted hectare went through two periods of increase, first in the 1960s and 1970s, and then more drastically in the last 10-15 years. This increase in turnover per hectare is thought to be brought about by the increase in yields obtained during the same period. When these were plotted together on a graph (Figure 2-16), the slopes followed each other very closely, particularly since 1950. In fact, the two variables have been strongly correlated since 1950 (Figure 2-17) [r = 0.9445], with the increase in turnover per hectare being driven by increases in yields.

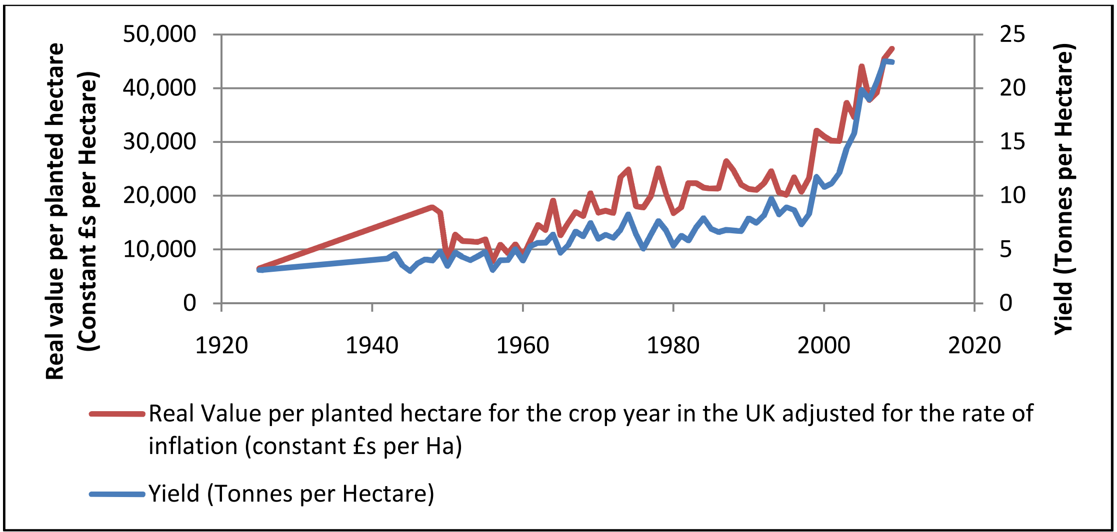


Figure 2-16 *Trends in the Real value per planted hectare and yield for the UK strawberry crop.*

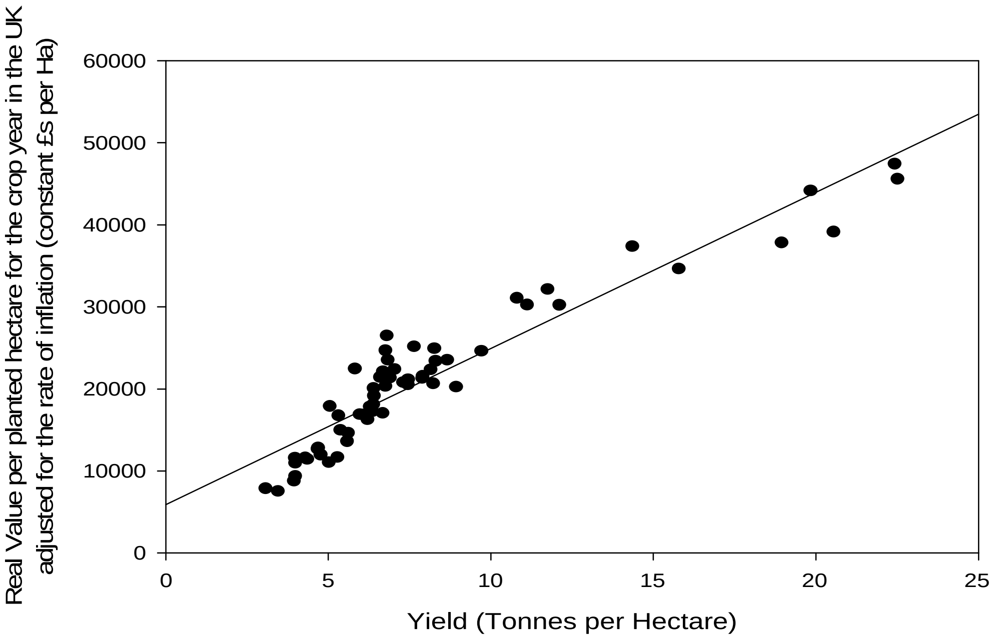


Figure 2-17 *Correlation between the real value per planted Hectare (this is a measure of turnover) and yield between 1950 and 2009 for the UK strawberry crop.*

2.3.2.2. Strawberry imports

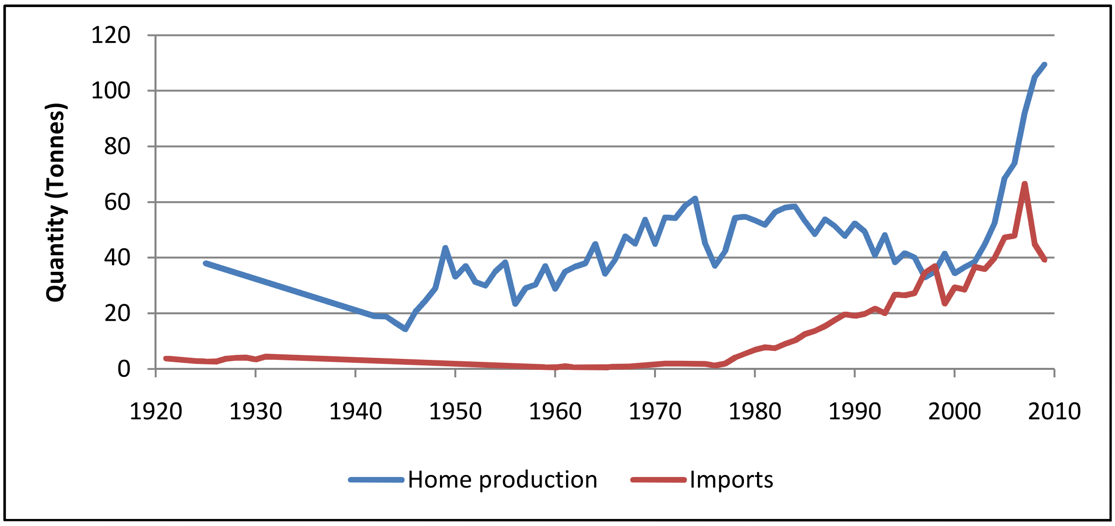


Figure 2-18 Quantity of home grown and imported strawberries. Data were available only at UK level.

Foreign grown strawberries have been imported to the UK throughout the 90 years covered by this study (Figure 2-18). Strawberry imports were lower in quantity than the British grown market, except during 1997 & 1998, when imports overtook home production. As of 2009, home grown production outstripped imports by 3:1.

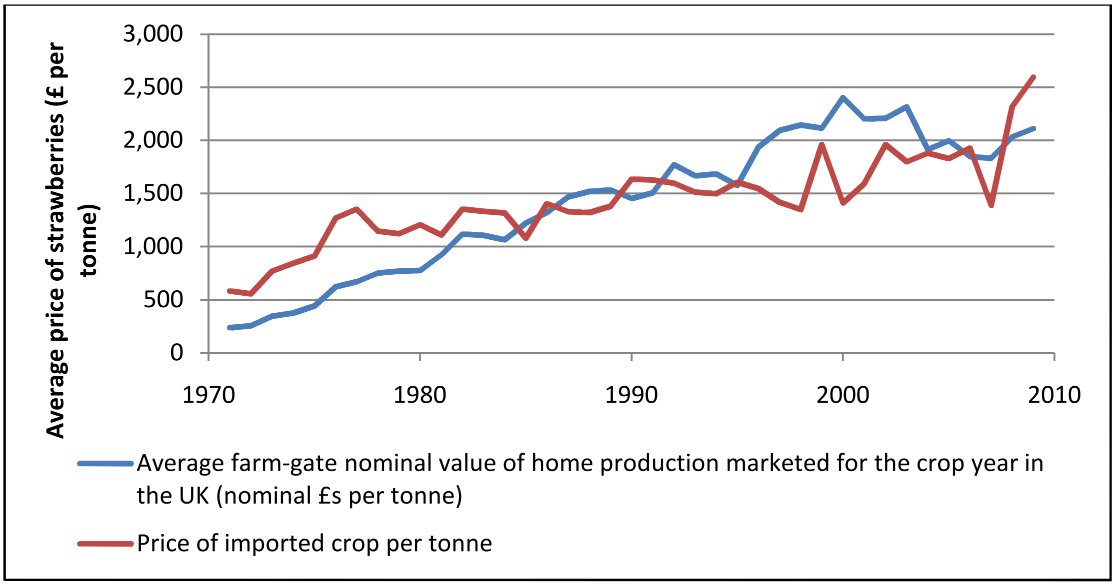


Figure 2-19 Price of home grown and imported strawberries. Data were only available at UK level.

The costs per tonne to the retail sector, of home grown and imported strawberries, have on a number of occasions overtaken each other throughout the last forty years

(Figure 2-19). Since 2007, imported strawberries have become more expensive than home grown strawberries.

2.3.3 Change in production methods

2.3.3.1. Use of cultivars

The earliest records of the proportion of strawberry cultivars used were from 1948. For the next 14 years, Huxley's giant was the dominant variety, whilst Royal Sovereign was the next most widespread variety used. This latter variety had been developed in the previous century (Darrow, 1966). The "Cambridge" varieties dominated the sector throughout the 1960s and 1970s. Elsanta became the most popular variety in the early-1980s (Beech and Simpson, 1989), and has retained dominance of the British market since then.

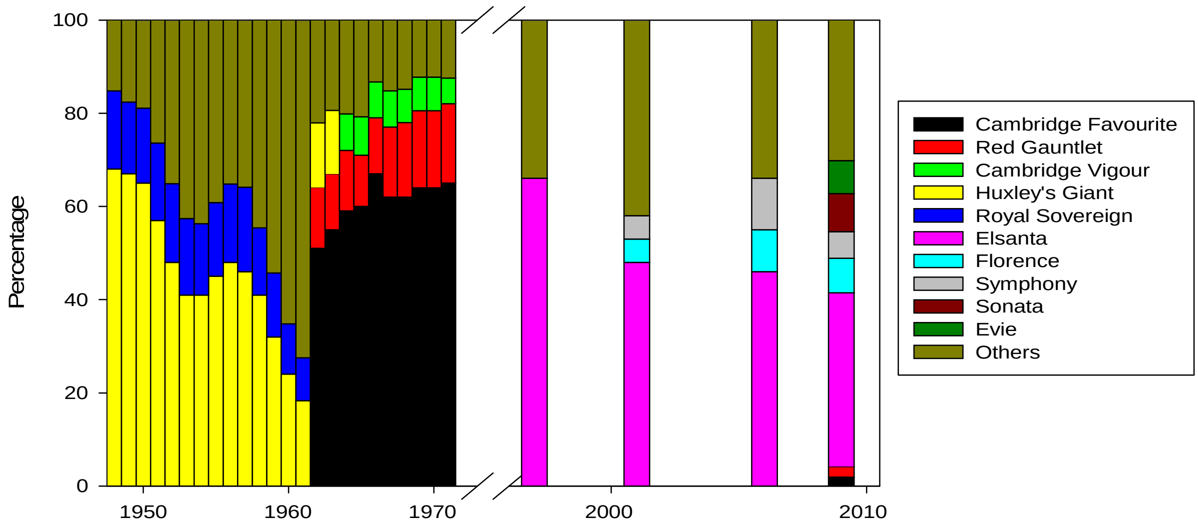


Figure 2-20 The use of cultivars between 1948 and 2009. Data were fragmented, with no records being available between 1972 and 1996. In most cases only data for the main two or three varieties were available.

More recently, everbearer varieties such as Sonata and Evie have become more common, being responsible in part for the extension of the season from 6 weeks to 6 months (Figure 2-21). The July crop, which until the 1960s consisted of around 80% of the entire year's crop, now amounts to only around 20% of the season's crop;

almost 40% of the crop is now harvested from August onwards thanks in part to the use of everbearer varieties.

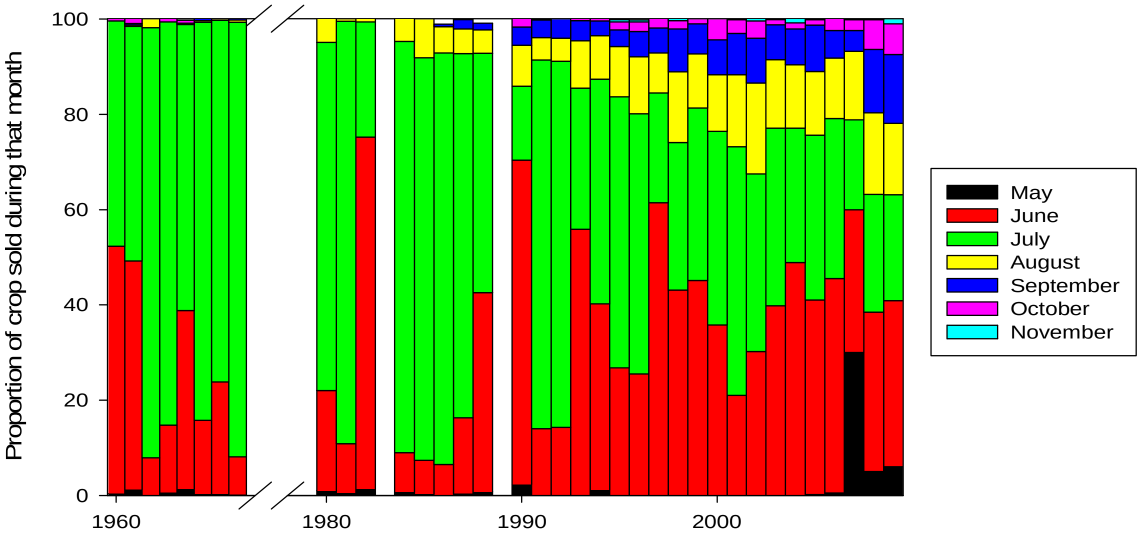


Figure 2-21 Proportion of fruit harvested during the different months of the year. Data for 1968-79 were not available.

2.3.3.2. Use of protection

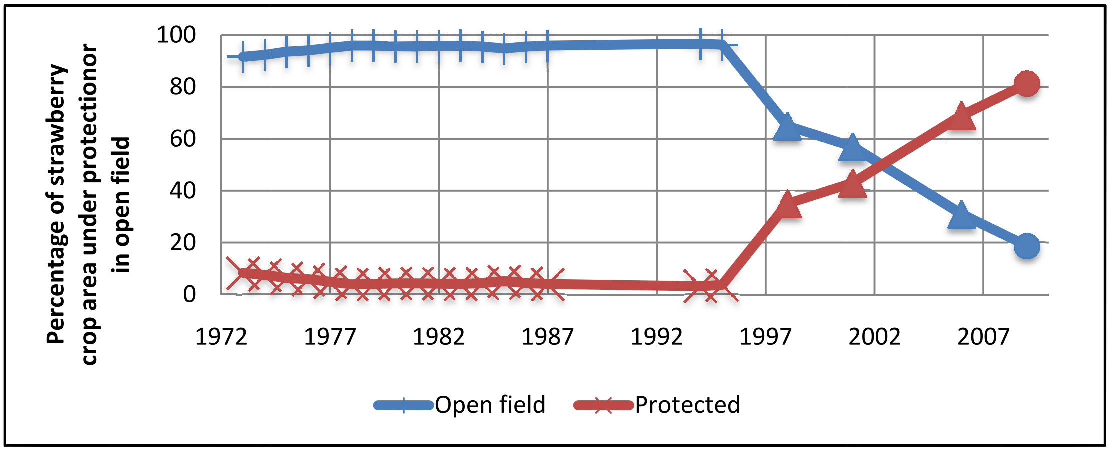


Figure 2-22 Proportion of strawberry cultivation (land area) under protection and in open ground (unprotected). Data marked by + or **x** *were taken from the yearly horticultural censuses; data points marked by a ▲were obtained from the Pesticide usage survey reports; data marked by a ● were obtained from the grower survey carried out as part of this study (section 4.3.1.2.1).*

The use of protection, though present in the past, has become widespread only since 1996. Whilst the protection used prior to 1996 consisted mainly of French tunnels, cloches, and a few glasshouses, from 1996 Spanish tunnels with their multispan system have become more common. Consequently, open field cultivation has become less common, with the latest estimate in 2009 being less than 20% of the total crop area of strawberries.

2.3.3.3. Pesticide usage

Pesticide usage has increased gradually since data first became available in 1965. Whereas in 1965 up to 11% of the strawberry crops were not sprayed with pesticides, this figure had decreased to less than 2% by 2006 (Figure 2-23).

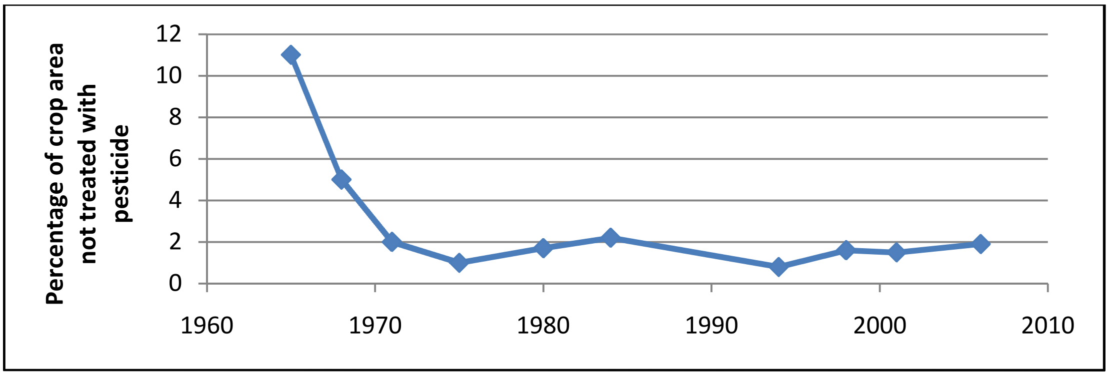


Figure 2-23 Land not sprayed with pesticides (this includes fungicides). Data obtained from Pesticide usage reports.

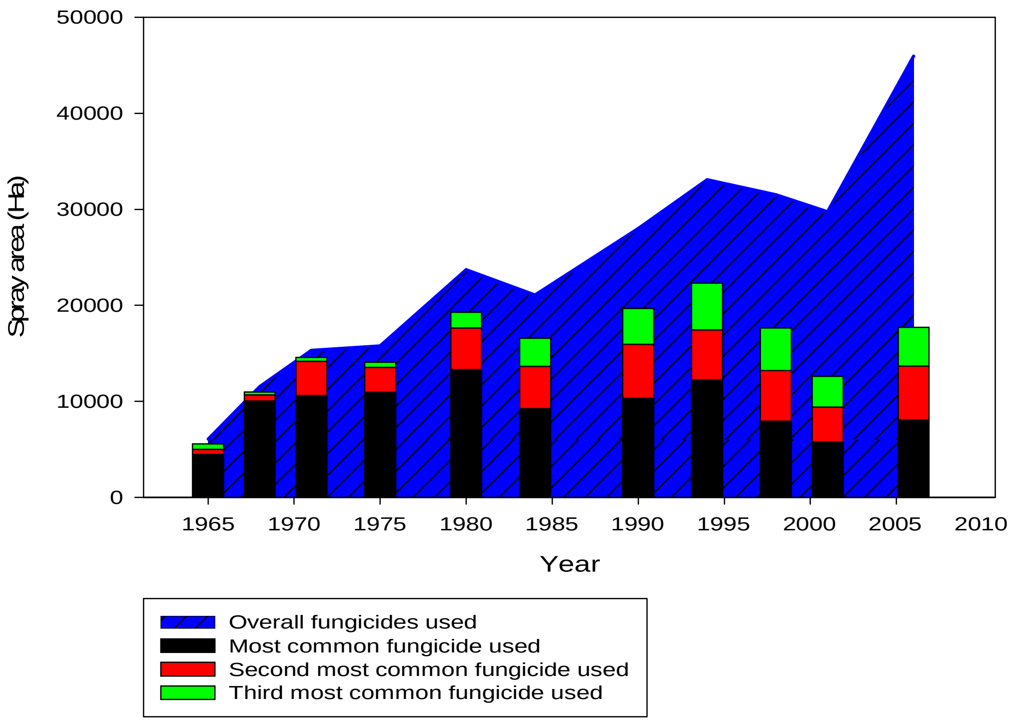


Figure 2-24 Spray area for 3 main fungicides used and the overall total spray area for all fungicides used. These data were obtained from the Pesticide usage reports for Soft Fruit crops.

The spray area for fungicides has also increased from 6,058 ha in 1965 to 45,960 ha in the last survey carried out in 2006 (blue line in Figure 2-24). This value is higher than the area of land cultivated for strawberries since it takes into account multiple sprays per season. As a result, the ratio of spray area to crop area has also increased consistently since records were first taken in 1965 (Figure 2-25). This can be used as a measure of the number of times the crop is sprayed every year. The range of fungicides has also increased and, whereas the most common fungicide before 1980 accounted for more than half of the overall spray area for combined fungicides, this decreased gradually over the next three decades, such that the most common fungicide in 2006 accounted for less than one-fifth of the combined spray area for all fungicides (Figure 2-24).

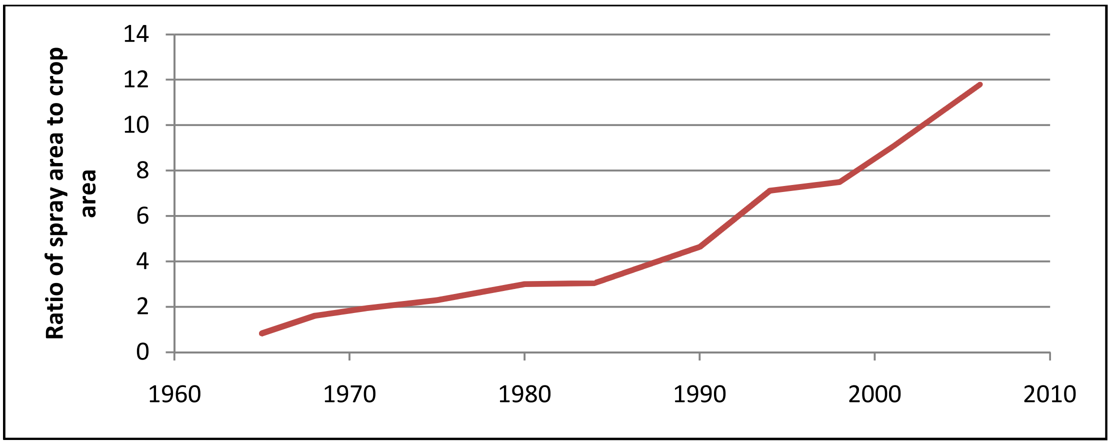


Figure 2-25 Ratio of spray area to crop area for the UK between 1965 and 2006. This value could give an indication of the number of times the crop is sprayed during the season.

The fungicides used over the years have also changed in importance and quantity (Table 2-4). Table 2-5 shows the uses for which these fungicides can be applied and whether they are in Annex I of EC Directive 91/414, making them legal to use in the EU.

Table 2-4 The three main fungicides recorded (from left to right) in the 11 Pesticide usage reports carried out by MAFF/DEFRA between 1965 and 2006

Year			
1965	[redacted]n	Captan	Su[redacted]
1968	[redacted]nid	Thiram	Di[redacted]
1971	[redacted]nid	Benomyl	Su[redacted]
1975	[redacted]nid	Benomyl	Chlor[redacted]
1980	[redacted]nid	Vinclozolin	Be[redacted]
1984	[redacted]nid	Vinclozolin	Tria[redacted]
1990	[redacted]nid	Bupirimate	Vin[redacted]
1994	[redacted]nid	Bupirimate	Ipr[redacted]
1998	[redacted]nid	Myclobutanil	Ipr[redacted]
2001	[redacted]anil	Dichlofluanid	Fenh[redacted]
2006	[redacted]anil	Fenhexamid	Bup[redacted]

Table 2-5 Uses of the various fungicides and whether they are listed in Annex I of EC Directive 91/414 (updated to 14/01/2011).

Fungicide	**Target organism**	**Annex I inclusion**
Benomyl	A foliar fungicide used to control a wide range of Ascomycetes and Fungi Imperfecti in a wide range of crops	Excluded
Bupirimate	A pyrimidine fungicide active against powdery mildew	Excluded
Captan	A dicarboximide fungicide widely used on edible and ornamental horticultural crops	Included
Chlorothalonil	A fungicide used to control a wide range of diseases on a broad range of crops.	Included
Dichlofluanid	Fungicide used to control a wide range of diseases including scab, brown spot, Botrytis spp., Alternaria spp. and storage diseases	Excluded
Dinocap	A protectant fungicide for powdery mildew control	Excluded
Fenhexamid	A fungicide used to control Botrytis cinerea and related pathogens in fruit, vegetables and ornamentals	Included
Iprodione	A fungicide used to control Botrytis, Minilia, Sclerotinia and other diseases in a wide range of crops	Included
Myclobutanil	A fungicide used to control Ascomycetes, Fungi Imperfecti and Basidiomycetes in a wide range of crops	Excluded
Sulphur	A fungicide, foliar feed and acaricide with a variety of uses including the control of scab on top fruit, powdery mildew on fruit and cereals, and mites on a range of crops	Included
Thiram	A fungicide used as a seed treatment to control "damping off" (Pithium sp) and as a spray to control other fungi such as Botrytis. Also pesticide degradation product.	Included
Vinclozolin	A fungicide used mainly on oilseed rape, vines, fruit and vegetables to control Botrytis, Monolinia and Sclerotinia spp.	Excluded

2.3.3.4. Impact of protection and pesticide use on yield

The use of protection and pesticides is correlated to the increase in yield of the strawberry crop (Figure 2-26). The yield increased as a greater proportion of the crop area went under protection, obtaining a correlation coefficient (r) of 0.901. The yield was also correlated to the increase in ratio between the spray area and crop area (indicative of the number of spray applications per season), obtaining a correlation coefficient (r) of 0.869.

The ratio of spray area to crop area also increased as a larger proportion of the crop area went under protection, and the two were found to be correlated, obtaining a correlation coefficient (r) of 0.887. Thus it is not clear whether the increase in yield came as a result of the increase in the two other variables independently of each other, or whether it was solely related to the increase in the protected area, which in turn influenced the increase in the ratio of spray area to crop area.

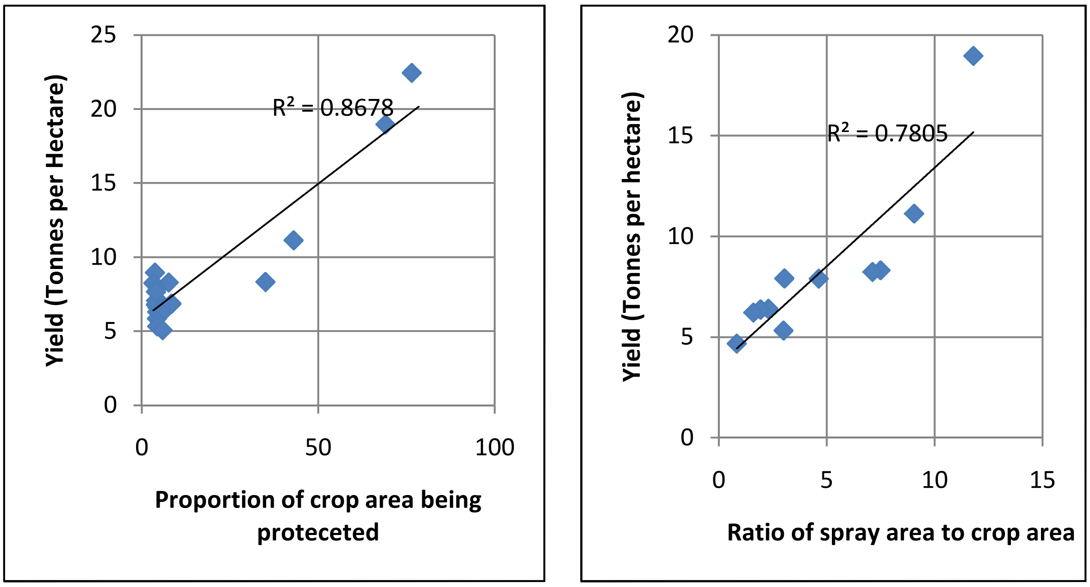


Figure 2-26 Correlation between the yield and the proportion of crop being protected (left), and the ratio of spray area to crop area (right). These data are available at UK level.

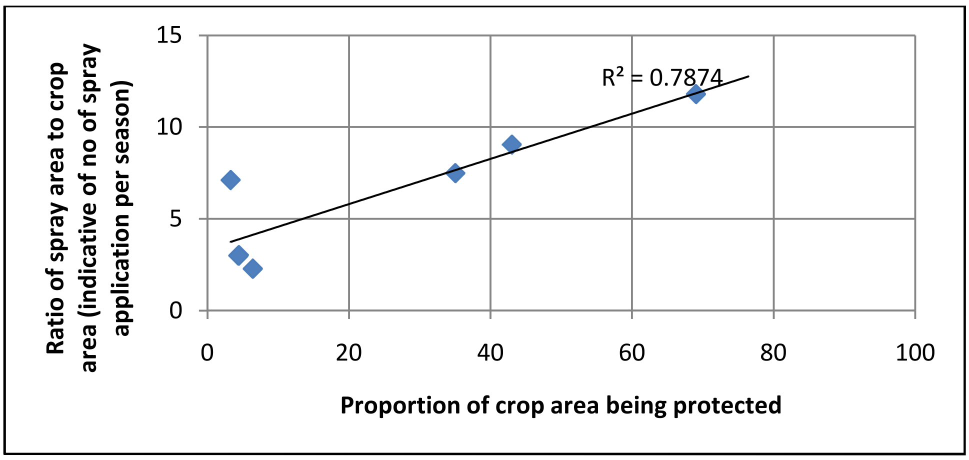


Figure 2-27 Correlation between the ratio of spray area to crop area and the proportion of crop being protected. These data are available at UK level.

2.4. DISCUSSION

The strawberry sector has gone through significant change during the 90 years covered by this study. Changes have not only taken place in the distribution of the sector throughout Great Britain, but also to production methods, crop yields, the size of farms, and even the length of the season. In order to describe these changes, the 90-year period covered by this study is further divided into three phases, following evidence obtained from the data described earlier on in this chapter. Whilst the timelines for the three phases are not fixed, and often overlap, changes in productivity and cultivation methods have been observed which eventually affected the growth or decline of the sector during that period.

2.4.1 First phase: 1920 to the 1940s

This earliest phase represents the most primitive phase of strawberry cultivation covered by this study. Production, though widespread in the 1920s and 1930s, was simple with plants being grown in the ground in rows (Mann and Ball, 1927, Harris *et al.*, 1934) and occasionally in glasshouses (Small, 1928). Notwithstanding the existence of specialised varieties, disease-resistance was not yet well understood (Harris *et al.*, 1934), and fungal diseases were widespread in strawberry cultivation (British Mycological Society, 1929, Ellis, 1970). Many of the diseases that are now easily controlled were then new and were still being described (Ballard and Peren, 1923, Small, 1928). Though some methods of controlling disease had been tested, these were mostly at the experimental stage (Moore, 1936), and the only prophylactic means of controlling strawberry disease was through heat treatment of the soil by burning, which would not serve as a deterrent if disease came in later by aerial means or on the plants themselves.

All of this contributed to low yields, which were then highly influenced by prevailing weather conditions (Mann and Ball, 1927) and the latter's influence on disease incidence which was already acknowledged during that time (King and Harris, 1940). In England, the yearly variation in yield was found to be greatest during this phase (Figure 2-12), making strawberry cultivation at this time risky due to the potential losses involved. This, together with the consistently low yields obtained (less than 5 tonnes per hectare) and impact of the Second World War on British farming, led to a fall in the total crop area. During the war, most farming land was focused on producing staple food crops to make Great Britain self-sufficient; as a result, the strawberry sector declined in importance.

2.4.2 Second phase: 1940s to 1996

The start of this phase and the end of the previous one overlap, and there is insufficient evidence to draw a clear line between the two. Data for the first phase were not available for all variables, and some data such as yields for Scotland and economic data for the UK were almost entirely absent up until the mid-1940s. Notwithstanding this, enough evidence exists to suggest a gradual change in the sector which was complete by the mid to late fifties. One of the greatest driving forces for change during this period was plant disease. This drove the development of disease-resistant varieties which enabled growers to obtain higher yields and lower their year to year variation in yields (see Figure 2-12).

Development of disease resistant varieties came from two main sources. Sir Rowland Biffin, from the University of Cambridge, developed the “Cambridge” varieties in the 1930s and 1940s that dominated the sector in the “second phase”, and Robert D. Reid, from the Scottish Horticultural Research Institute, developed the “Auchincruive”, “Talisman” and “Red Gauntlet” varieties (Reid, 1949, Darrow, 1966). In the latter’s case, one of the largest drivers of his work was the presence of Red Core that had been responsible for widespread losses in certain strawberry-growing areas in Scotland (Wormald, 1941). This disease had become widespread, and was first described in 1940 as being attributed to the parasitic fungus of *Phytophthora fragariae* (Hickman, 1940).

The increase in the British strawberry crop area in the beginning of this phase was probably caused by a combination of two factors. Firstly, the return of the agricultural workforce after the war picked up strawberry cultivation from where they had left it before they were conscripted; and secondly, the high average real farm gate value of the crop at that time reached £4500 in constant pounds in 1948 (almost double the 90-year mean)(Figure 2-14). Unfortunately, economic data for 1926 to 1947 were missing, so the trend leading up to and just after the war could not be analysed in more detail.

During the next 5 decades, the yield steadily increased threefold, through the introduction of disease resistant varieties and the increased use and variety of fungicides. These cultivation practices also led to a reduction in the yearly variation in yield, particularly on English farms, as they enabled growers to reduce the impact of weather on their crop, by reducing crop loss from plant disease. English farms nevertheless had higher yields, due to the harsher climatic conditions found in Scotland. In fact Scottish farms are more susceptible to lower temperatures and heavier rain than farms in the south and east of England, where most of the strawberry crop area is concentrated. Thus England has better climatic conditions for growing strawberries.

During this phase, the focus of strawberry cultivation in Great Britain started shifting from the northern part of East Anglia to the Southeast. The sector in Cambridgeshire, Lincolnshire and Norfolk went into decline. Strawberry and fruit production in these regions were giving way to arable production, as this region gradually became the centre of the arable sector in England (Ilbery, 1988). At the same time, the strawberry sector in the southeast of the country, particularly Kent (Beech and Simpson, 1989), became more important. This partly occurred due to the setting up in Kent of one of the first producers' cooperatives in Great Britain in the 1970s. This cooperative focused on marketing strawberries and soft fruit, and helped consolidate the market for its grower members. As the producers' cooperatives grew stronger, and more were set up, this impacted on the market and the way strawberries were sold. Through them, the supermarkets could avoid sourcing their strawberries from the wholesale market, and by the early-1990s, 60% of the sales of fresh strawberries were through these cooperatives (by now called marketing groups) (Carter *et al.*, 1993). One of the impacts they had was to influence growers to lengthen the season by using different varieties, including everbearers (Hancock, 1999). By the mid-1990s, the season had lengthened from 6 weeks (in the late seventies) to 4-5 months long.

The average real farm gate value of the crop during this phase stayed relatively constant, fluctuating between 2,000 and 3,000 constant pounds per tonne, except for a short phase in the mid-1970s when the value passed 3,000 constant pounds per tonne. On the other hand, the real value per planted hectare, after being adjusted for inflation, increased in the 1960s and 1970s due to the increase in crop yield. This meant that growers now had an increasingly larger turnover in their income from each hectare of strawberry crop they cultivated. Notwithstanding this, the crop area started to decrease in the 1980s, halving in size by 1997. At the same time, strawberry farms in certain areas increased in size, particularly in those areas that experienced growth in the sector, such as Kent, Staffordshire and Kincardineshire in Scotland. The decrease in the crop area of Great Britain is thought to have occurred due to the decline of the pick-your own and wholesale markets, putting out of business numerous small growers (Carter *et al.*, 1993).

2.4.3 Third phase: 1997 -2009

Since the late-1990s, the British strawberry sector has reached production levels never seen before in the UK. The combined output of strawberries more than doubled over a 13-year period, even though the crop area has remained stable at around 4,000ha. The reason for this change is thought to be the increased use of protection in strawberry production. Up until 1995, less than 5% of the crop area in Great Britain was under protection; however, by 1998 this had increased ten times to around 35%. Around the same time, crop yields increased drastically, and the starting point for this change was pinpointed down to 1997. Since then, yields have increased by 2½ times, and the yearly variation in yield has also decreased drastically in both England and Scotland. Even the discrepancy in yields obtained between English and Scottish farms has decreased greatly to just ±8.6% from ±53%. All of this change has been brought about by putting more of the crop under protection. This has led to controlled growing conditions, where the higher temperatures obtained within these structures enhance plant productivity and increase yields. Moreover, by covering the crop, the strawberries are shielded from the prevailing weather, which in Scotland could be particularly variable. This enabled the productivity gap between Scottish and English farms to narrow. As a result, Scottish strawberry production has since boomed, increasing its contribution to the total strawberry crop area in Great Britain from 10% in 1996 to almost 25% in 2009. However, this increase has not occurred proportionately across Scotland. All of the increase took place in the southeast counties of Perthshire, Fife and Angus, whereas the rest of the strawberry sector in Scotland went into decline. Strawberry cultivation in Lanarkshire and the Lothian regions has all but disappeared.

In England and Wales, the focus of the sector continued shifting towards the Southeast, West Midlands, and Northwest regions, in particular, Kent, Herefordshire & Worcestershire and Staffordshire. These counties took up a greater proportion of the strawberry crop area, together contributing for about 50% of the crop area for England and Wales by 2009. The increase in the crop area in these and the Scottish counties was due to an increase in the size of holdings involved in strawberry production in these areas rather than to an increase in the number of farms involved in strawberry cultivation. In fact, whilst the latter continued to fall, the remaining farms increased in size.

The increase in the size of strawberry farms was probably brought about by the increase in the real value of the crop per planted hectare, which in turn was brought about by the increase in yield. Thus the increase in turnover worked as an incentive to the remaining growers to increase in size. Whilst it is not clear from these data whether these increases occurred on both farms using protection and those growing their crop in the open field, it is assumed that the biggest changes occurred on farms using protection, since this is thought to be the driving force behind the increases in yields experienced in British strawberry farms since 1997. Thus the farms using protection were larger, had higher yields and, in turn, greater turnover.

Whilst the turnover experienced by strawberry farms increased during this phase, the real value of the crop actually decreased to the lowest recorded levels since 1948, dropping below the 2,000 constant pounds per tonne mark for the first time in 2006 and 2007. The impact this has had on the sector could not be determined from the data available, since no data were available on farm expenses, to determine the mean profit margin of strawberry farms. Some suggest that the decrease in the real price of the crop has been driven down by the supermarket chains (Hingley, 2005, Taylor and Fearne, 2009) that now dominate the sales of fresh strawberries. Rogaly (2008) also suggests that the increasing cost of labour has reduced profit margins for strawberry businesses to such an extent that an increase in size is the only way to survive, by supplying greater volumes, through the intensification of production and becoming involved in the packing and primary processing not only of their own products, but also of imports.

The ratio of home grown to imported strawberries has almost always been tipped in favour of the home grown crop. Imported strawberries only contribute in part to the overall sales of strawberries in the UK market. Moreover, imports tend to cover the months when home-grown strawberries are not available (Carter *et al.*, 1993). The price of home grown strawberries has often been higher than that of imported strawberries; nevertheless, sales have been tipped in favour of the former. The driver behind the demand is probably the popularity of home grown strawberries. Though data for this were not available, it appears that the popularity of the home grown crop has driven up demand for the product, such that the sector has increased production by spreading the crop over a 6-month period. This was made possible by a combination of the use of protection to cover the crop and bring the season forward, the use of everbearer varieties to extend the season into autumn and, finally, by the use of fungicides that helped decrease fruit loss from disease incidence. The extension of the season also meant that growers were applying 10-12 spray applications during the season by 2009 compared to the 3-4 in the 1980s. The range of fungicides available in these last ten years was also wider than in the 1970s (Figure 2-24). Notwithstanding this, a good number of the main fungicides used by the sector have been excluded from Annex I of EC Directive 91/414, and the fate of the remaining chemicals following the publication of EC Regulation No 1107/2009 concerning the placing of plant protection products on the market, is still uncertain. Therefore in the absence of new approved fungicides, the sector might not be able to sustain the growth it has been experiencing in the last 15 years.

2.5. SYNTHESIS

The use of government held statistical records can give a good insight into the restructuring of a sector, if a wide enough range of data covering a number of decades are available for analysis. This chapter has in fact shown how a number of cultivation practices can change the structure and dynamics of a sector and the businesses involved. In this case, three practices have had drastic impacts on crop yields. Of these, the most important has been the use of protection. This triggered a number of changes that transformed the sector. Firstly, yields and subsequently turnover per hectare were more than doubled within a decade. Farms became larger and the focus of the sector changed to new areas that had until then been disadvantaged by bad weather. The divide between the Scottish and English strawberry sectors narrowed, and the former even increased their share of the UK crop. British strawberries became a fixed item in supermarkets during half of the year and this ensured that the crop was distributed over a longer time span rather than flooding the market in a short time frame.

As a consequence of this growth, polytunnels have become a common sight in the counties that have experienced growth in the sector. This has created a number of conflicts with local communities that see these structures as environmentally damaging, and a threat to the cultural landscape of the British countryside. A lot of negative publicity has also been created in the media, which often report cases of legal battles between farmers and local councils on the former’s right to set up or retain these structures (Hickman, 26 June 2006, BBC News, 2010b, Doward, 4 July 2010). Issues of food security are brought into the argument by the farming lobby, and the ability of farmers to grow food without protection is often raised in support of these structures.

It might be argued that growing strawberries has little impact on food security since it is often considered as a luxury dessert crop. However, the restructuring that has occurred in the strawberry sector since 1996 is quite representative of what has happened in other parts of the horticultural industry. Whilst strawberries can still be grown without the use of polytunnels, it would not be possible to sustain the type of yields that have been achieved in the last 15 years in their absence. Moreover they have enabled the sector to increase the output of crop (in tonnes) by keeping the same area of land. And all this has come at no cost to the consumer since the real farm-gate value of strawberries has never been as low as during the last ten years.

The significance of these conflicts could have a great impact on the sector in the future, particularly the recent court ruling in Herefordshire on the case of the Wye Valley Action Association against the Herefordshire County Council (Doward, 4 July 2010). This resulted in the court overturning the latter's decision in granting planning permission to a business in 2008 "for polytunnels covering 255 hectares, of which 54 hectares would be covered at any one time". Strawberry businesses could choose to move their business to counties where polytunnels are not opposed, resulting in the migration of the strawberry sector to other regions, taking with them jobs and a valuable source of income to the local economy (considering that the strawberry sector in 2009 was worth £231m). In the worst case scenario, the bad publicity could tarnish the image of the British strawberry sector, and tip the balance in favour of imports, that would gradually out-compete the British strawberry.

Whatever happens, conflicts such as these between the conservation movement and the farming lobby are bound to have an impact on food security and, more importantly, on the British farming community's ability to produce food at low cost to the consumer. This will become even more important in view of climate change and its potential impacts on crop yield and plant disease, in the increasing absence of effective and safe plant protection products.

Chapter 3 Plant disease and the UK strawberry sector

3.1. INTRODUCTION

Many strawberry diseases have highly localised distributions. Nevertheless, there are a number of diseases that are found worldwide. *Mycosphaerella fragariae* is the most widespread leaf disease, with *Diplocarpon earlianum*, *Phompsis obscurans*, and *Podosphaera macularis* also being quite common. *Botrytis cinerea*, *Phytophthora cactorum* and *Colletotrichum acutatum* are the most widespread fruit rots, whilst *Phytophthora fragariae* and Verticillium wilt are the most common root fungal diseases (Hancock, 1999).

Pesticides can be used to control most of the diseases, but the key to good control is good sanitation. Maintaining good air flow, minimizing standing water, starting with clean planting stock and utilizing resistant varieties is also vital to the control of most fungal pathogens (Hancock, 1999). With the impending threats of climate change, and the ever more restrictive use and lists of available pesticides, controlling plant disease could be one of the greatest challenges facing strawberry farmers in the future.

With this in mind, the aim of this chapter is to study the role of plant disease in shaping the UK strawberry sector since the 1920s, when records of disease outbreaks first started being collected by the ministry then responsible for Agriculture. The geographic distribution of disease will be studied for the four main diseases and compared to the distribution of the strawberry sector during that time. Other factors affecting disease incidence will also be assessed, such as the use of susceptible cultivars during various times, prevalent weather patterns and introductions of new diseases. The threat of alien diseases on the British strawberry sector in the past and future will be assessed, by studying the efficacy of the British quarantine system in stopping the entry of new diseases into Great Britain. This will be achieved by using *Colletotrichum acutatum* as a case study.

For simplicity, the chapter is divided into two. In the first part, the historiography of plant disease affecting the UK strawberry sector is analysed. In the second part, the effectiveness of UK Phytosanitary controls is assessed.

3.2. HISTORIOGRAPHY OF THE MAJOR PLANT DISEASES AFFECTING THE UK STRAWBERRY INDUSTRY

3.2.1 Plant disease in the UK strawberry sector

Strawberry diseases have been studied in the UK for over a century, with records of diseases on strawberries being published as early as 1906 (Smith). By the late 1920s, the most common diseases were *Podosphaera macularis* (Powdery mildew), *Mycosphaerella fragaria* (Leaf spot) and *Diplocarpon earlianum* (Leaf scorch) (British Mycological Society, 1929). Other diseases, which are now easily controlled, were then new and were still being described (Ballard and Peren, 1923, Small, 1928), such as *Phytophthora fragariae* (strawberry red core) which rapidly spread throughout the UK as a result of the susceptibility of contemporary cultivars (Hickman and English, 1951b)

3.2.1.1. Powdery mildew – Podosphaera aphanis

Powdery mildew is one of the most common foliar fungal diseases of strawberries and occurs wherever strawberry plants are grown (Bhardwaj and Sharma, 1999). The disease attacks all the above soil parts of the plant including flowers, fruit and leaves. Whilst yield losses may result from infection of flowers and fruit, severe foliar infection damages leaves and reduces photosynthesis by giving rise to a thick covering of mycelium, necrosis, or even defoliation (Maas, 1998).

3.2.1.1.1. Epidemiology and Disease incidence

The development of powdery mildew is favoured by low light intensity (Xiao *et al.*, 2001), as higher light intensities have been found to reduce germination and hyphal growth (Amsalem *et al.*, 2006). The optimal temperature range for conidial germination and conidial germ tube growth ranges approximately between 15 and 25°C (Xiao *et al.*, 2001, Blanco *et al.*, 2004, Amsalem *et al.*, 2006).

Powdery mildew on strawberries has been reported as a common disease throughout Great Britain since the late 1920s (British Mycological Society, 1929, Dennis and

Foister, 1942). Notwithstanding its widespread distribution, it was not a major disease until the introduction of production under protection (Jordan and Hunter, 1972). More recently, it has become significantly more severe with the increased use of polythene tunnels (Dodgson *et al.*, 2008). This is because the incidence of Powdery mildew on strawberries is much higher under protected cultivation than in the field (Maas, 1998, Xiao *et al.*, 2001), except during the part of the season when temperatures became higher than the threshold for disease development (Xiao *et al.*, 2001).

3.2.1.2. Grey Mould – Botrytis cinerea

Botrytis cinerea is one of the most destructive diseases of strawberry both worldwide (Maas, 1998) and in the UK (Berrie, 2004). It often appears in the field before harvest, particularly when there is persistent wetness in the crop, and reduces yield and quality both pre- and post-harvest.

3.2.1.2.1. Disease incidence

Grey mould caused by *B. cinerea* is known to have been common in the UK since the late 1930s (Wormald and Harris, 1938, Dennis and Foister, 1942). Its incidence is highly correlated to the amount of rainfall 11-30 days prior to the first harvest, which corresponds roughly to the period from early bloom through to the green fruit stage (Maas, 1998). Xiao *et al.*, (2001) found that just by covering strawberry plants by tunnels, disease incidence decreased by 88 to 94%. This was found to be even lower than the incidence of Botrytis fruit rot in a crop in the open field that was subjected to a 7-day spray program (Xiao *et al.*, 2001). The same authors found that another effective way of reducing disease incidence was to use wider within-row plant spacing, reducing Botrytis fruit rot by 26 to 42%.

3.2.1.3. Verticillium wilt – *Verticillium dahliae*

Verticillium wilt of Strawberry occurs throughout the temperate zones of the world and is most prevalent and destructive in irrigated semi-arid regions (Maas, 1998). The pathogen can affect a whole plantation at once and, in extreme cases, virtually all plants can be affected. In these instances, a plantation immediately becomes unprofitable and is often grubbed in the planting year (Raffle and O’Neill, 2006).

3.2.1.3.1. Disease incidence

The first record of Verticillium wilt in England is given in a report from the Cambridge horticultural station in 1932 which states that severe losses were caused in the King's Lynn district and at Cambridge (Keyworth and Bennett, 1951). Just after the Second World War in 1945-1947, a major outbreak of the disease in several nurseries caused a reduction of up to 75% of the crop runners, and some nurseries were even abandoned following the outbreak (Keyworth and Bennett, 1951). Notwithstanding the improvements in strawberry production over the years, the disease still remains probably the most devastating of all the soil-borne strawberry diseases in the UK (Raffle and O'Neill, 2006).

The degree of disease incidence in a field is related to the quantity of inoculum present in the soil, which is in turn related to the number of times the field was cropped with strawberries, or another plant that is susceptible to *Verticillium dahliae* (Harris and Yang, 1996, Raffle and O'Neill, 2006). Harris & Yang (1996) also found that the disease was more common at sites with a history of vegetatively propagated crops than at sites that had only supported crops grown from seed. Due to the importance of soil based inocula as a source of the disease, growing the plants in soil-less substrates such as peat and coconut fibre (coir), which are almost always free of the fungus, have become a widespread means of production (Lieten *et al.*, 2004, Raffle and O'Neill, 2006).

3.2.1.4. Strawberry red core – *Phytophthora fragariae*

Red core (or red stele as it is sometimes referred to) was thought to be first observed in Scotland in 1920 (Maas, 1998), although records exist of other outbreaks around the same time in the Tamar valley in Devon (MAFF, 1922). The source of the disease was not clear at that time and was attributed to a number of pathogens (MAFF, 1926, Wardlaw, 1927). It was later described in 1940 as being attributed to the parasitic fungus of *Phytophthora fragariae* (Hickman, 1940). Nowadays, it occurs throughout the world, in most countries where strawberries are grown (Maas, 1998). It is a major disease in areas with cool moist climates. Losses from red core tend to be more serious where strawberries are grown as a perennial crop (Maas, 1998), and in the UK alone the annual loss to the industry from *Phytophthora fragariae* is in the range of £3-4 million (Perry and Raffle, 2004).

Infection arises from the release of zoospores into waterlogged soil, either in soils with a light soil texture that are prone to waterlogging, or else in regions with a high rainfall (Hickman and English, 1951a). In the latter case, the disease will still develop in a soil with completely free drainage as long as the rainfall in high enough.

3.2.1.4.1. Disease incidence

Disease incidence of red core in strawberries is usually more severe when the preceding winter has been cool and wet. This happens because in extended periods of ideal conditions, the diseased plants continue to produce zoospores over a long period, leading to an accumulation of inoculum in the soil (Maas, 1998). Reid (1949) even observed a relationship between the disease severity of red core in strawberries and the number of days on which rain actually falls. He observed that “in the most severely affected districts in the west of Scotland, during the 6 months October to March (182 days) rain may fall on 90-130 days. At the lower figure damage is not usually marked, but in years when the higher figure is approached, loss from red core is likely to be heavy wherever infection is present.” Hickman and English (1951a) also observed that although *Phytophthora fragariae* was widely distributed across Great Britain by the late- 1940s, thanks in part to the interchange of runners between one strawberry-growing district and another, the disease did not occur uniformly throughout the strawberry-growing districts. This was found to be related to inherent soil moisture, either due to poorly draining soils in certain areas or else through the incidence of a higher rainfall, or both (Hickman and English, 1951a).

3.2.1.4.2. UK Phytosanitary legislation related to red core

Phytosanitary legislation to control the disease started in England with the enactment of the “Sale of Strawberry and Black Currant Bushes Order” in 1946. This legislative tool prohibited the sale of uncertified plants, which was thought to be the main cause of the spread of the infection. The order was revoked and replaced by the Red Core Disease of Strawberry Plants Order of 1952 (revised in 1957) (Baker, 1972). These last two orders made the disease notifiable to MAFF and introduced official “scheduling” of any land known to be infected. By the end of 1961, notices had been served on over 640 commercial and non-commercial premises declaring the specified land to be infected (Baker, 1972). These orders were revoked and replaced by the Plant Health (Great Britain) Order 1987 (revised in 1993). This last revision restricted the practice of scheduling any land known to be infected to nurseries selling runners with Plant Passports[9].

The Plant Health Order 2005 reconfirmed *Phytophthora fragariae* as a listed pest, although it removed the requirement to schedule any infested land. Propagation (passported) crops are now only required to be visually inspected for symptoms and, under the voluntary Plant Health Propagation Scheme[10] (PHPS), growers have to sign a declaration that the land is not known to have been ever infested with red core.

3.2.2 Materials and methods

The data consisted of unpublished datasets of plant disease that were collected by Plant Health and Seed Inspectors (PHSI) as part of data collecting exercises held under four different MAFF schemes since 1920. These datasets were held at the Food and Environment Research Agency (FERA), either in archives in their central library at Sand Hutton or as soft copies in Excel sheets or databases. Access to the datasets was obtained in fulfilment of one of the aims and objectives of this study which was partly funded by FERA through a Seedcorn grant.

3.2.2.1. Disease datasets

Four different datasets were made use of as follows:

3.2.2.1.1. Monthly summary of fungus and allied diseases occurring in England and Wales. 1920-1973

This first dataset consisted of monthly reports collected by the Ministry of Agriculture, Food and Fisheries between 1920 and 1973. These records reported disease incidence in the major crops, throughout England and Wales, as part of the surveillance work of MAFF inspectors responsible for plant health, during their routine inspections. Strawberry was one of the crops included in the surveillance

[9] A document required to accompany the movement of certain plants and plant products within the EU, certifying that they are free of specified quarantine pest (ANONYMOUS 1992. Commission Directive 92/103/EEC of 1 December 1992 amending Annexes I to IV to Council Directive 77/93/EEC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. *In:* THE COMMISSION OF THE EUROPEAN COMMUNITIES (ed.) *L 363 , 11/12/1992.* Brussels: Official Journal of the European Union.

[10] The PHPS is a Scheme that aims to provide commercial growers with planting material descended from stock that is proven both in terms of health and vigour (FERA 2009. Plant Health Propagation Scheme. *In:* THE FOOD AND ENVIRONMENT RESEARCH AGENCY (ed.). Sand Hutton, York.

scheme. The outbreaks were reported as a record of incidence of disease in a particular county, village or farm and in many cases, a record of the cultivars used was given. Due to the nature of the reports, an indication of the time of the year when the disease was prevalent was obtained. The descriptions of the outbreak also gave an indication as to the distribution and severity of the disease in that month or year, which was then converted into a numerical figure through this study according to Table 3-1.

The data in this dataset were tabulated in an excel sheet and records of an outbreak were entered as a record of disease incidence. Therefore, for example, four outbreaks in a county in May 1926 were given a value of 3. References to minor disease incidence, such as a few infected plants in a farm, were not considered.

Table 3-1 The severity scales used to classify the disease outbreaks

Severity index	Description
1	**No record of the disease during that month**
2	**Record in a single farm or in a few farms and being of low significance**
3	**Many records within a single county or widespread in one or two counties**
4	**Many records in different counties and being of epidemic proportions**

The length of the time series meant that the names of diseases and sometimes even locations changed throughout the dataset. These were corrected and cross-checked so that the correct name for the location, pathogen or disease was used.

3.2.2.1.2. ADAS pest and disease incidence reports. 1972-1978

The second dataset consisted of yearly records of disease outbreaks in the UK from 1972 to 1978 from the ADAS regional agricultural science service annual reports (e.g. West Midlands report or south east England report). Whereas the regions where a particular disease outbreak occurred were mentioned, the exact counties were not. Moreover, no indication of a month was given when the disease occurred.

3.2.2.1.3. Scheduling of land infected with strawberry red core. 1968-2001

This list consisted of records of land scheduled according to the "Red Core Disease of Strawberry Plants Order" of 1957. Only records from 1968 onwards were available and used. The records included the grid reference indicating the location of the farm, the date of scheduling and the area of the land scheduled. The dataset was obtained as a hard copy list from the Central Science Laboratories records held at FERA.

3.2.2.1.4. Records from Pathdiary database. 1986-2004

This dataset was obtained from computer based databases held by the authorities responsible from plant health during the 1980s and 1990s. The database was called *Pathdiary* and was kept between 1984 and 2002. It was collected by the Ministry of Agriculture, Fisheries and Food in the 1980s at the Harpenden Laboratory and later at the Central Science Laboratories in York. In it were recorded the outbreaks of quarantine diseases in the UK between 1983 and 2002. In total, 159 entries for *Phytophthora fragariae* were recorded. Each record included the date the entry was made, the farm location (through an address or name of farm or farmer), the disease and cultivar name. On other occasions, there was also a reference to the cultivation method, infection level and action taken by the Plant Health and Seed Inspectors. In almost all cases, the farm was identified and a post code obtained indicating the exact location of the outbreak.

3.2.2.2. Analysis of data

Following the collation of the various disease datasets, the diseases for which the largest amount of information was available were shortlisted to be used for further analysis. Four diseases were selected including: *Verticillium* wilt, *Podosphaera aphanis, Botrytis cinerea and Phytophthora fragariae*. Data extracted from the original datasets included locations of the outbreaks, cultivars used, severity and frequency of outbreaks. The outbreaks were divided by county in order to study the spatial distribution of disease and reasons for the differentiation sought. ArcGIS® was used to plot the diseases at county level. Spatial analysis was also used to test the clustering of disease outbreaks and to determine whether the distribution of disease outbreaks was random.

Chi-square tests were used to determine whether the quantity of disease outbreaks in a particular location was related to the size of the industry in that county. This was achieved by determining the strawberry crop area in a county, by taking this as a proportion of the national total crop area and multiplying it with the England and Wales total disease count to obtain a value for the expected disease count. The chi test was then performed on the actual number of disease outbreaks obtained and the expected disease count which was obtained using the crop areas.

A number of graphical methods were used to display the results including tables, scatter plots, vertical bar charts, stacked bar charts and clustered column charts.

For *Phytophthora fragariae*, grid references were obtained from the scheduling list of the individual farms and fields where the outbreaks were recorded, including the area of land affected. These were converted into coordinates and used to plot the individual locations using ESRI® ArcMap™ 9.2. Soilscapes™ was also used to study the influence of soil type on the incidence of strawberry red core in England between 1968 and 1997. The latter layers contained data on the drainage capacity of predominant soils. This layer was joined with the *Phytophthora fragariae* outbreaks layer in order to study the influence of soil type on the incidence of red core in strawberries. The following drainage categories were available in Soilscapes™ and are described as follows:

- **Freely draining soils** absorb rainfall readily and allow it to drain through to underlying layers.
- **Slightly impeded drainage** refers to soils with a tight, compact deep subsoil that impedes downward water movement; after heavy rainfall, particularly during the winter, the subsoil becomes waterlogged.
- In soils with **impeded drainage** the effect is more severe and winter water logging results in very wet ground conditions.
- In the uplands, many soils have a greasy surface peat layer that holds water through the winter. These soils are described as having **surface wetness** and can be reasonably dry beneath.

- In low-lying sites, permeable soils are often affected by high ground water that has drained from the surrounding landscape. They are described as **naturally wet**.

3.2.2.2.1. Linking red core incidences with weather events

Weather data were collected for the time period covering disease incidence in order to study the link between the October to March rainfall and the incidence of red core according to Reid (1949). Daily rain datasets were collected for a number of counties. The data were obtained from the Met Office's 'Data Extractor' search engine, using the 'MIDAS Land Surface Observation Stations Data' Datasets which are available to download after prior registration with the MetOffice[11]. Daily records of rainfall were downloaded for an average of 7-10 weather stations per county. The 5 counties were chosen on the basis of the amount of records available from the list of farms scheduled for red core. The locations of the weather stations were chosen to include areas where strawberries are known to be grown and where data were available for a long uninterrupted period during 1920-2007. After being re-arranged manually due to many gaps where data were not collected during certain periods, the daily weather data for the various weather stations were then averaged such that a mean daily record was obtained for each of the counties. These rearranged datasets were then uploaded into GenStat® 12th edition and a model written to calculate the October to March total annual rainfall, and the number of days between October and March with at least 1mm of rainfall.

[11] British Atmospheric Data Centre, 2006. Available from http://badc.nerc.ac.uk/data/ukmo-midas

3.2.3 Results

A total of over 3500 records of outbreaks were obtained from the studied datasets, representing just over 30 different diseases. Of these, about 2500 records belonged to four diseases: *Podosphaera aphanis*, *Botrytis cinerea*, *Verticillium dahliae* and *Phytophthora fragariae*. Over 1700 records belonged to the latter disease alone. Records were obtained for 45 counties from England and Wales. No data were available for Scotland.

The results in this section have been divided into two parts. In the first, *P. aphanis*, *B. cinerea* and *V. dahliae* are grouped together, while in the second part *P. fragariae* is analysed separately since much more data were available for this disease, enabling a more in-depth analysis. For each part, the geographic variation of disease outbreaks is first analysed, followed by seasonal and varietal influences on the diseases.

3.2.3.1. Podosphaera aphanis, Botrytis cinerea and Verticillium wilt

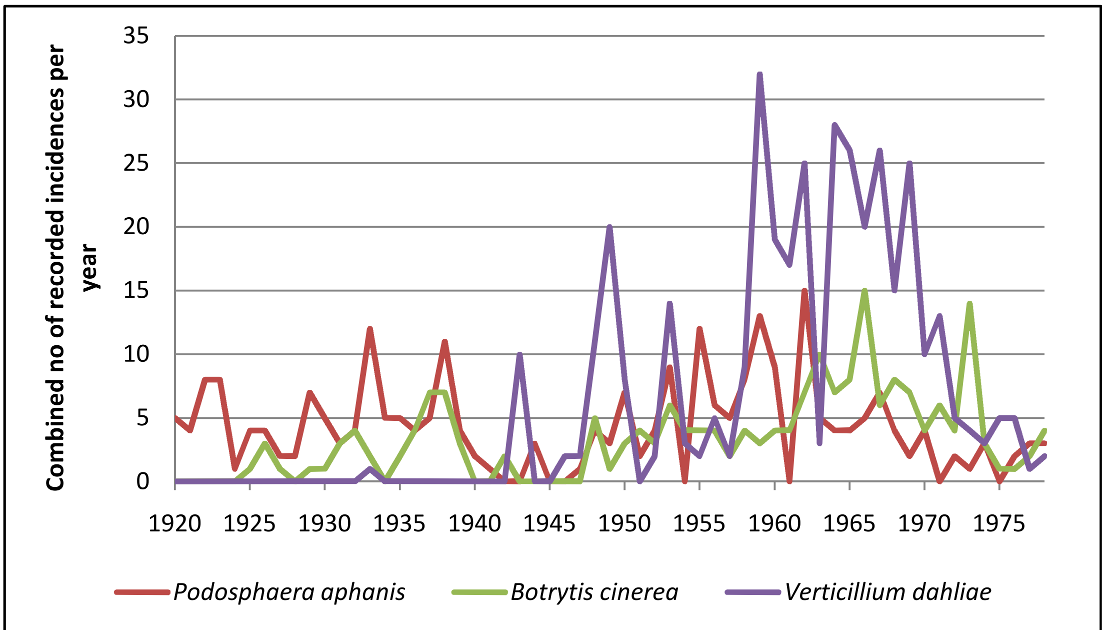


Figure 3-1 Annual record of outbreaks for three of the most common strawberry diseases in England and Wales. Each entry along the plot shows the total number of outbreaks (y-axis) recorded throughout England and Wales for that disease during that year.

Powdery mildew from *P. aphanis*, Grey mould from *Botrytis cinerea* and Verticillium wilt were three of the most common diseases of strawberry between

1920 and 1973. The only other disease to be more common was Red core caused by *P. fragariae*. Records of powdery mildew and grey mould were available from earlier on in the 1920s and 1930s, however Verticillium wilt in strawberries was first recorded in these databases in 1933 in Norfolk, and only became widespread from the 1940s onwards. The incidence of these three strawberry diseases within England and Wales was found to vary both temporally (Figure 3-1) and spatially (Figure 3-2).

Disease records varied spatially irrespective of the size of the strawberry industry in that county. While some diseases were very common in some counties, they were almost absent in others (Figure 3-2). For instance, there were more records of *Powdery mildew* from *P. aphanis* in Somerset than in Kent, even though the area occupied by the strawberry sector in Kent during that time was 10 times larger than that occupied in Somerset. Variation also exists within the county with respect to disease incidence. For instance in Kent, *Verticillium* wilt was more common than diseases caused by *B. cinerea*, whilst there were only 4 recorded incidents of *P. aphanis* in 54 years. In contrast, virtually no records of Verticillium wilt exist from Northumberland, but the county had amongst the highest records of powdery mildew in England during that time period.

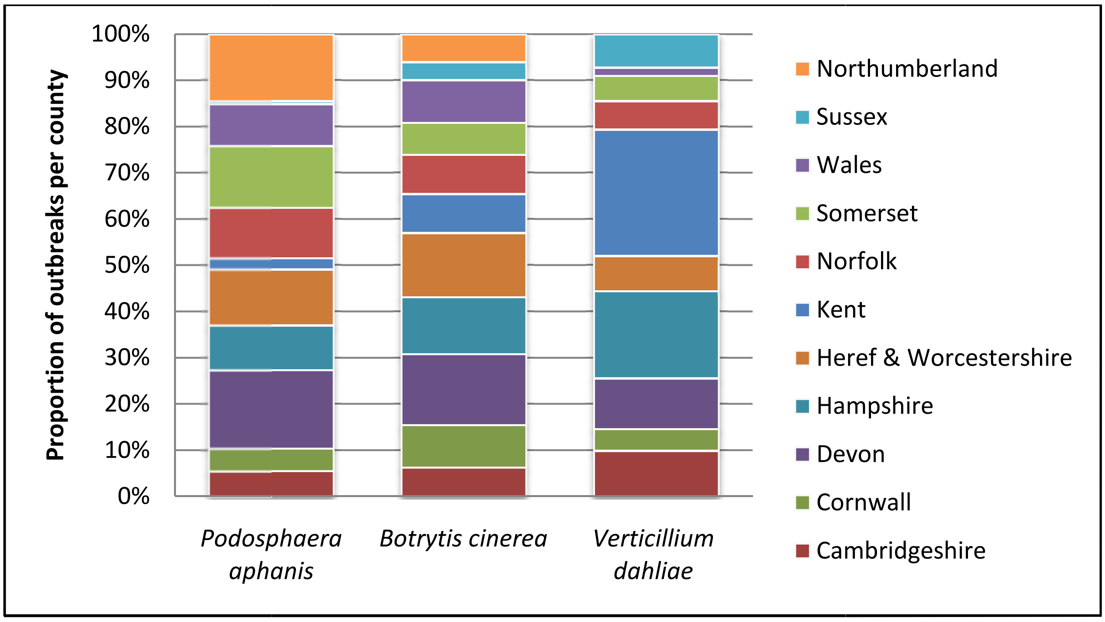


Figure 3-2 100% stacked bar chart showing the distribution of 3 diseases in the 10 areas with the highest relative disease count in England and Wales. The records are expressed as a percentage share for these counties of the whole England and Wales disease count for that particular disease.

Chi square tests carried out for ten different strawberry producing areas showed that for the three diseases, the size of the county's strawberry crop area was not the main determining factor affecting disease incidence (Table 3-2). Some counties such as Norfolk had an exceptionally low disease incidence even though they had one of the largest strawberry crop areas during that time. Consequently, the actual number of disease incidences recorded was much lower than the expected disease incidences, based on the size of the crop area alone.

Table 3-2 The number of disease outbreaks listed for the three diseases across 9[12] English counties and Wales. The value in brackets is the expected number of disease outbreaks based on the size of the strawberry sector within the different counties and Wales, taken as a proportion of the England and Wales total crop area between 1920 and 1973. Chi-tests were used to determine whether the actual and expected number of outbreaks were the same.

County	Powdery mildew from *Podosphaera aphanis*	Grey mould from *Botrytis cinerea*	Wilt from *Verticillium dahliae*
Cambridgeshire	9 *(37.9)*	8 *(29.2)*	27 *(55.5)*
Cornwall	8 *(3.8)*	12 *(2.9)*	13 *(5.6)*
Devon	28 *(4.3)*	20 *(3.3)*	30 *(6.3)*
Hampshire	16 *(18.9)*	16 *(14.6)*	52 *(27.7)*
Hereford & Worcestershire	20 *(15.4)*	18 *(11.9)*	21 *(22.6)*
Kent	4 *(44.7)*	11 *(34.5)*	75 *(65.5)*
Norfolk	18 *(46.4)*	11 *(35.8)*	17 *(68.0)*
Somerset	22	9	15

[12] Northumberland was dropped out for the chi-tests since the expected number of disease outbreaks for this county was too low, making the chi-test invalid.

County	**Powdery mildew from *Podosphaera aphanis***	**Grey mould from *Botrytis cinerea***	**Wilt from *Verticillium dahliae***
	(4.2)	*(3.2)*	*(6.1)*
Wales	15 *(3.2)*	12 *(2.5)*	5 *(4.7)*
Sussex	1 *(3.1)*	5 *(2.4)*	20 *(4.6)*
Chi tests	$P < 0.001$	$P < 0.001$	$P < 0.001$

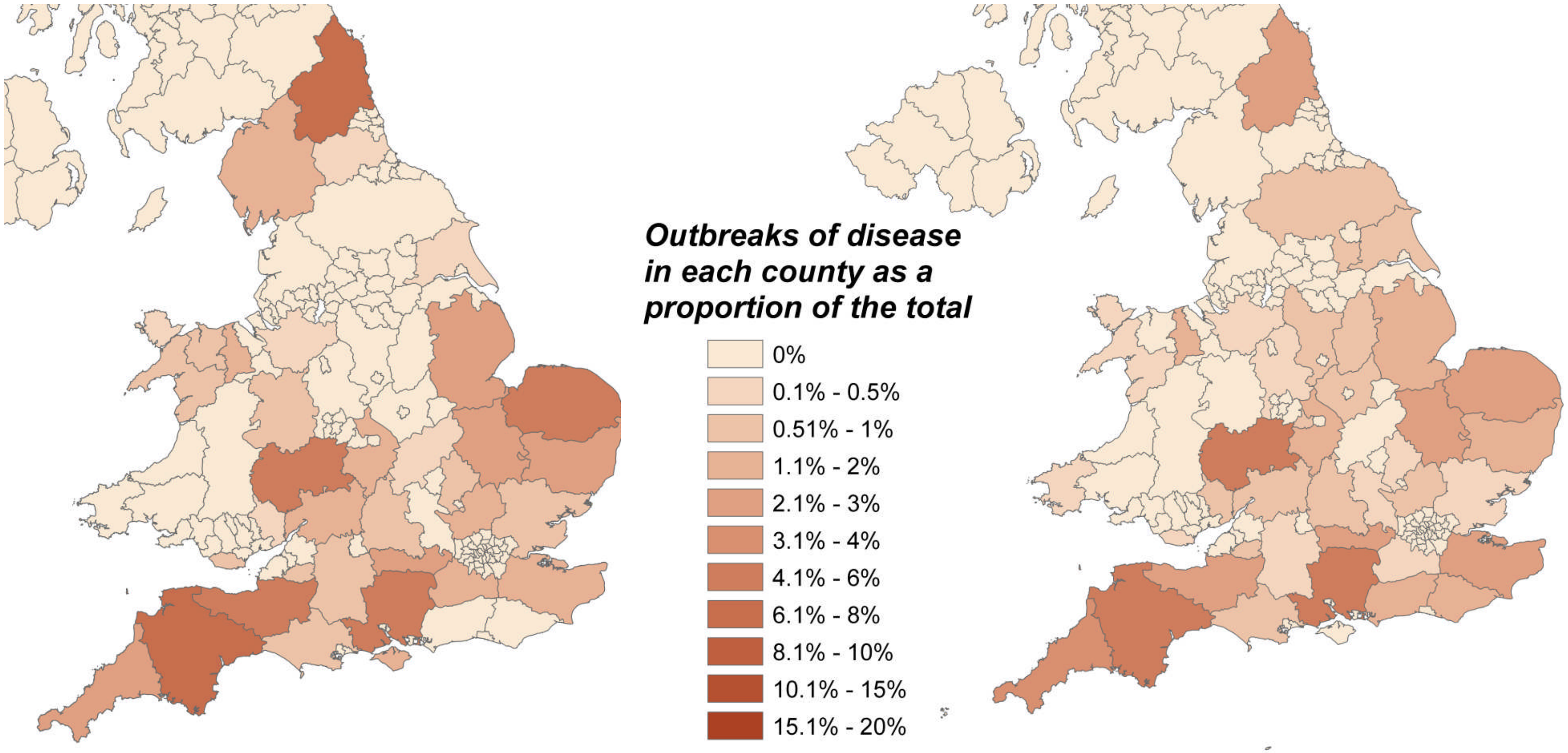


Figure 3-3 Distribution of outbreaks of powdery mildew in strawberries caused by Podosphaera aphanis (on left) and grey mould in strawberries caused by Botrytis cinerea (on right). Data represents the total disease count between 1920 and 1973, arranged by county. The values are displayed as a proportion of the total number of recorded outbreaks in England and Wales. Spatial autocorrelation using Moran's Index gave a value of 0.03 for both diseases, implying that there is less than 1% likelihood that this clustered pattern could be the result of random chance.

The locations of the outbreaks of the three diseases within England and Wales were plotted using ESRI® ArcMap™ 9.2 (Figure 3-3, Figure 3-4). Spatial autocorrelation on the three maps demonstrated that the clustered pattern of disease outbreaks could not have occurred by chance.

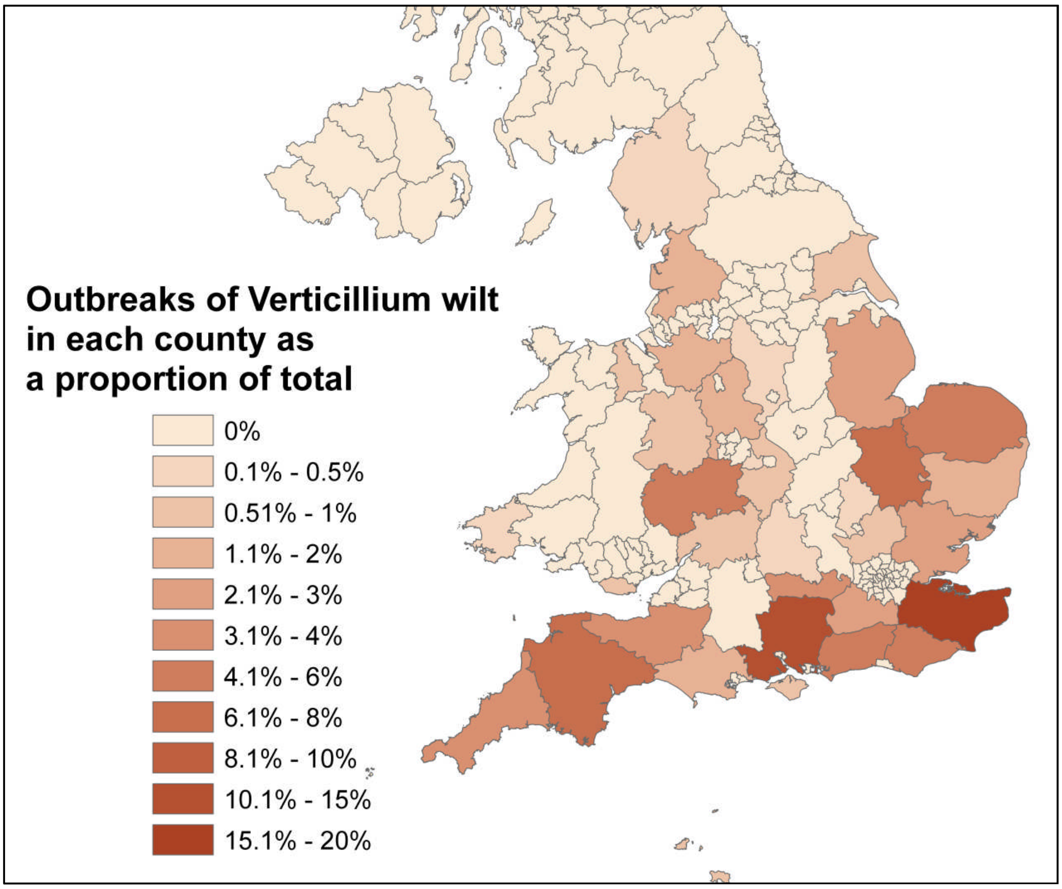


Figure 3-4 Distribution of outbreaks of Verticillium wilt in strawberries between 1920 and 1973, arranged by county. The values are displayed as a proportion of the total number of recorded outbreaks in England and Wales. Spatial autocorrelation using Moran's Index gave a value of 0.02, implying that there is less than 5% likelihood that this clustered pattern could have occurred by chance.

3.2.3.1.1. Seasonal vulnerability to disease

The seasonal distribution of the three diseases showed that June was the worst month with grey mould occurring mostly in June (Figure 3-6), and powdery mildew being widespread in both June and July (Figure 3-5). Verticillium wilt exhibited two peaks, in June and later September (Figure 3-7). The severity indices referred to earlier in Table 3-1 suggest that *P. aphanis* occurring later in the season in August was more severe, whilst *B. cinerea* was most severe in June. Verticillium wilt, on the other hand, was slightly more severe in June and August.

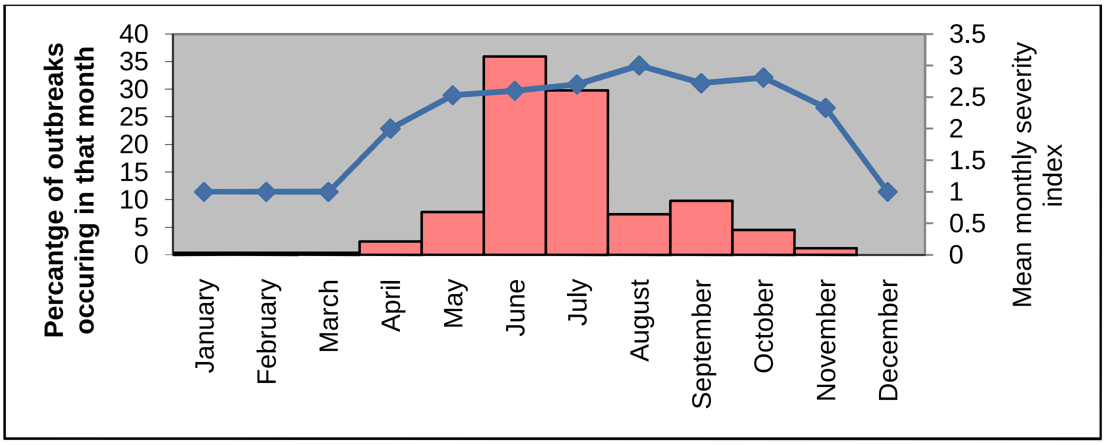


Figure 3-5 Vertical bar chart shows the time of the year when the outbreaks of P. aphanis occurred, whilst the blue scatter plot shows the mean monthly disease severity of the outbreaks during 1920 to 1973.

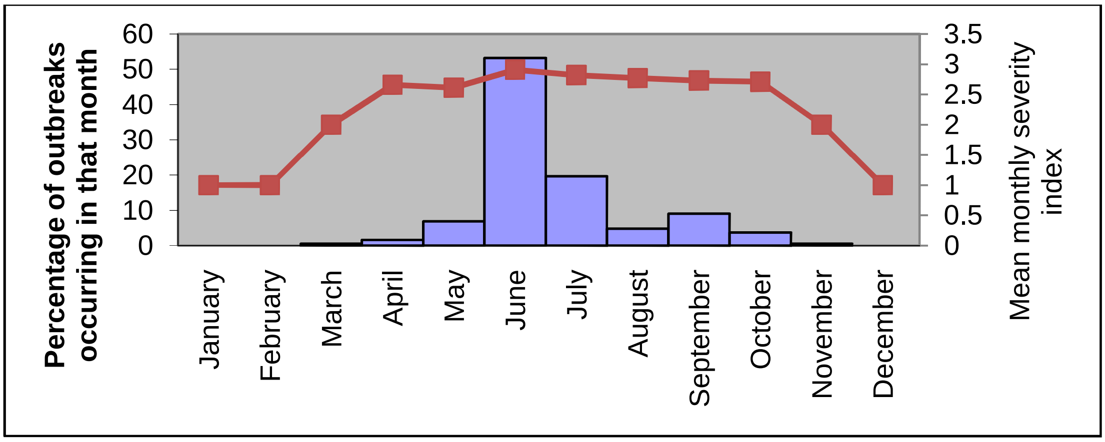


Figure 3-6 Vertical bar chart shows the time of the year when the outbreaks of B. cinerea occurred, whilst the scatter plot shows the mean monthly disease severity of the outbreaks during 1920 to 1973.

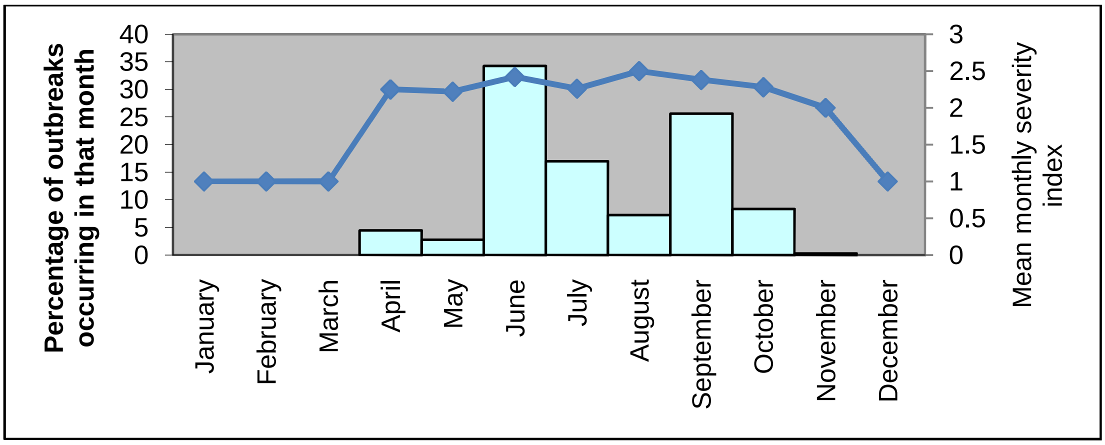


Figure 3-7 Vertical bar chart shows time of the year when outbreaks of Verticillium wilt occurred, whilst the scatter plot shows the mean monthly disease severity of outbreaks during 1920 to 1973.

3.2.3.1.2. Cultivars used and disease susceptibility

In 255 of the 800 incidences of the three combined diseases, the cultivars were known. Of these, 142 were cases involving Verticillium wilt. The cultivars found to be most susceptible to the latter disease were Huxley's Giant (23% of the records), Royal Sovereign (15% of the records), and Cambridge Vigour (13% of the records). For powdery mildew, 88 records of cultivars were obtained. Of these Royal sovereign was the most susceptible (40% of the records) followed by Sir Joseph Paxton's (12.5% of the records). Only in 25 cases of grey mould were the cultivar names available. Since this figure represents a very low proportion of the total for grey mould, further analysis was not undertaken.

The two most popular cultivars grown till the late 1950s were Huxley's Giant and Royal Sovereign (Figure 2-20). These were replaced in the early 1960s by Cambridge Favourite and Red Gauntlet (Figure 2-20). The five varieties with the largest number of records of outbreaks include both Royal Sovereign and Huxley's Giant, but neither Cambridge favourite nor Red gauntlet. In fact, the latter two cultivars only had 12 and 6 records of disease respectively.

Table 3-3 The five cultivars with the largest available number of disease records. Figures are the actual number and not percentages.

Cultivar	Total	Powdery Mildew	Grey mould	Verticillium wilt
Royal Sovereign	62	35	6	21
Huxley's Giant	39	2	5	32
Cambridge Vigour	24	5	1	18
Madame Lefevre	21	7	1	13
Cambridge Rearguard	15	0	1	14

In 26 cases, the diseases were recorded to occur under protection. This represents around 3% of the total number of recorded incidences for the three diseases. Of these

26 cases, 17 were cases involving powdery mildew, 7 for grey mould and 2 for Verticillium wilt.

3.2.3.2. Outbreaks of *Phytophthora fragariae* in the UK

Over 1700 records of outbreaks were obtained for *Phytophthora fragariae* in England and Wales. The data were obtained from three separate databases, one of which was the list of notices for scheduled land that contained 895 records of outbreaks and a total of 3660Ha of farmland that was infested with *P. fragariae* and subsequently notified to the authorities. On combining the three databases, most of these red core outbreaks were found to be in England, with the vast majority of records occurring between 1946 and 1995.

3.2.3.2.1. Spatial and temporal variation

The first records of an outbreak of red core obtained through this study were in May 1920 in Cornwall. By the Second World War, it had been recorded in 10 counties. Through this study, it was found to occur in over 40 counties in England and Wales. Distribution of the disease varied both temporally (Figure 3-8) and spatially (Figure 3-9).

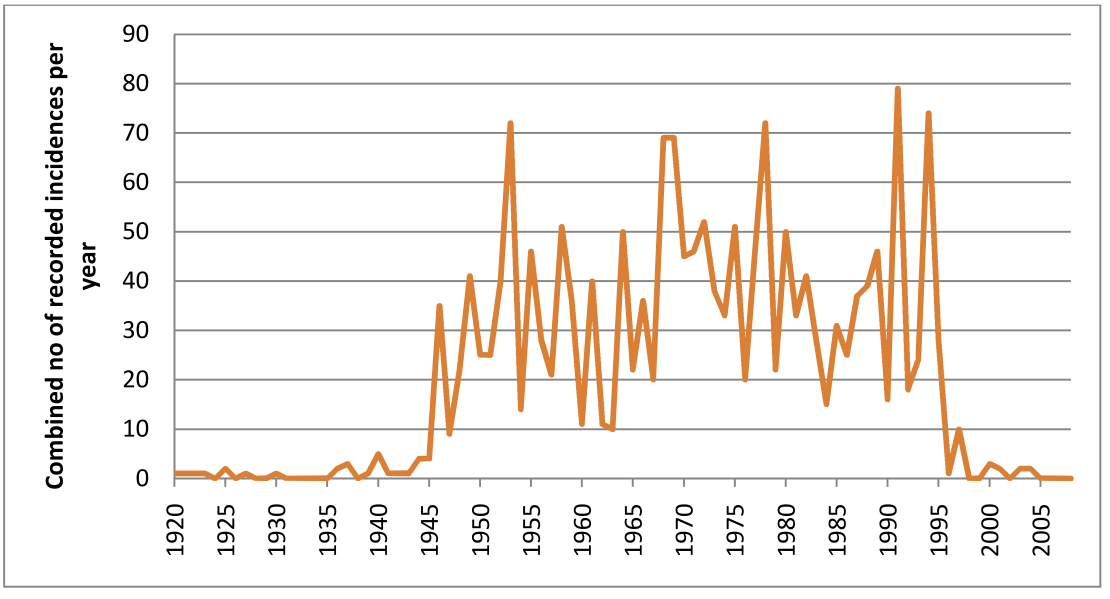


Figure 3-8 Annual record of outbreaks of Phytophthora fragariae in England and Wales. Each entry along the plot shows the total number of outbreaks (y-axis) recorded for that disease during that year.

Yearly fluctuation in disease incidence throughout the country is evident, not only on a regional scale but also on a county level. Spatial variation was also particularly evident, with the disease being very common in certain areas, irrespective of the size of the strawberry industry in that county. On comparing the expected number of outbreaks with the actual number of outbreaks (Table 3-4), most counties either have much lower or much higher than expected disease incidence. Cambridge and Norfolk had an actual disease incidence 4 to 5 times lower than the expected disease incidence. Cornwall, Devon, Hampshire and Sussex, on the other hand, had much higher actual disease incidence than were expected when taking into consideration the size of the strawberry sector in those areas. Kent was found to have the highest actual disease incidence, which was around 25% higher than the expected disease incidence.

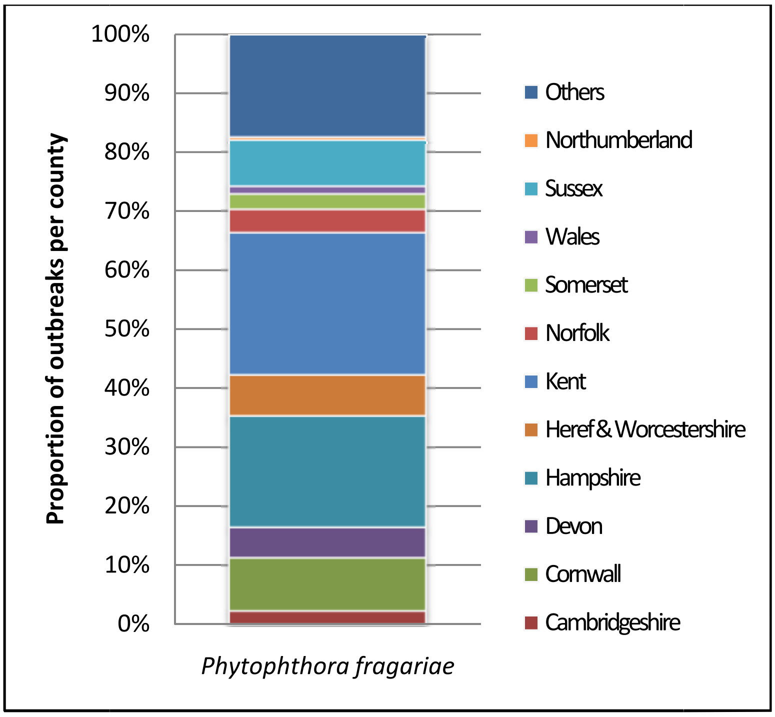


Figure 3-9 100% stacked bar chart showing the distribution of red core caused by Phytophthora fragariae in the main strawberry producing counties of England and Wales. The records are expressed as a percentage share for these counties of the whole England and Wales disease count for that particular disease.

Chi square tests carried out for ten different strawberry producing areas obtained a p-value below 0.001, suggesting that the size of the counties' strawberry crop area was not the main determining factor affecting the disease count (Table 3-4).

Table 3-4 The actual number of disease records listed for red core across 10 English counties. The value in brackets is the expected number of disease outbreaks based on the size of the strawberry sector within the different counties and Wales, taken as a proportion of the England and Wales total crop area between 1920 and 1973. Chi-tests were done to determine whether the actual and expected number of outbreaks were the same.

County	Incidences of red core from *Phytophthora fragariae*
Cambridgeshire	40 *(194.0)*
Cornwall	159 *(25.6)*
Devon	92 *(28.4)*
Hampshire	334 *(106.8)*
Hereford & Worcestershire	123 *(139.0)*
Kent	427 *(342.9)*
Norfolk	70 *(290.9)*
Somerset	46 *(35.0)*
Northumberland	9 *(7.9)*
Sussex	139 *(35.0)*
Chi tests	$P < 0.001$

Spatial autocorrelation using two different spatial statistical tools was conducted to test the clustering of the disease outbreaks (Figure 3-10). Both Moran's Index and the Cetis-Ord General G index showed high clustering of the disease outbreaks, indicating that there is less than 1% likelihood that the clustering of high values could have occurred by chance.

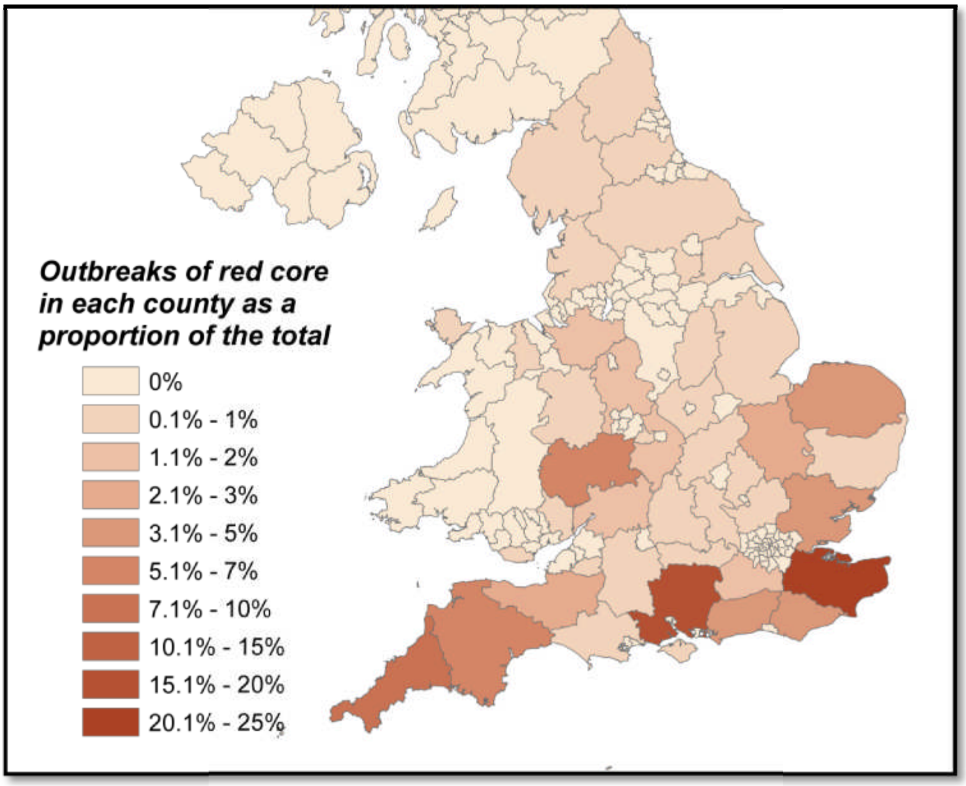


Figure 3-10 Distribution of the 1700 outbreaks of P fragariae between 1920 and 2004, arranged by county. The values are displayed as a proportion of the total number of recorded outbreaks in England and Wales.

3.2.3.2.2. Influence of weather and soil type on disease incidence

Environmental factors such as weather and substrate type have been shown to affect the incidence of *P fragariae* (Reid, 1949, Hickman and English, 1951a). In order to further investigate possible causes of the clustering of disease outbreaks, the prevailing soil types were plotted on Arcmap using Soilscapes™ (Figure 3-11). On restricting the data to the 5 counties that had the highest number of notices of scheduled land, the farms were found to be located on soils of four drainage capacities (Figure 3-12). The proportion of the different soil types on the infested land varied by county. The same was true for the proportion of the overall soil types for the whole county and, in some cases, this and the proportions of soil type in the infested land mirrored each other, such as in the case of Cornwall, Kent and Hampshire. This implied that there was no preference by farmers for cultivation on one soil type, but strawberries were grown wherever land was available to the farmers, i.e. on whatever soils were available for cultivation in that county.

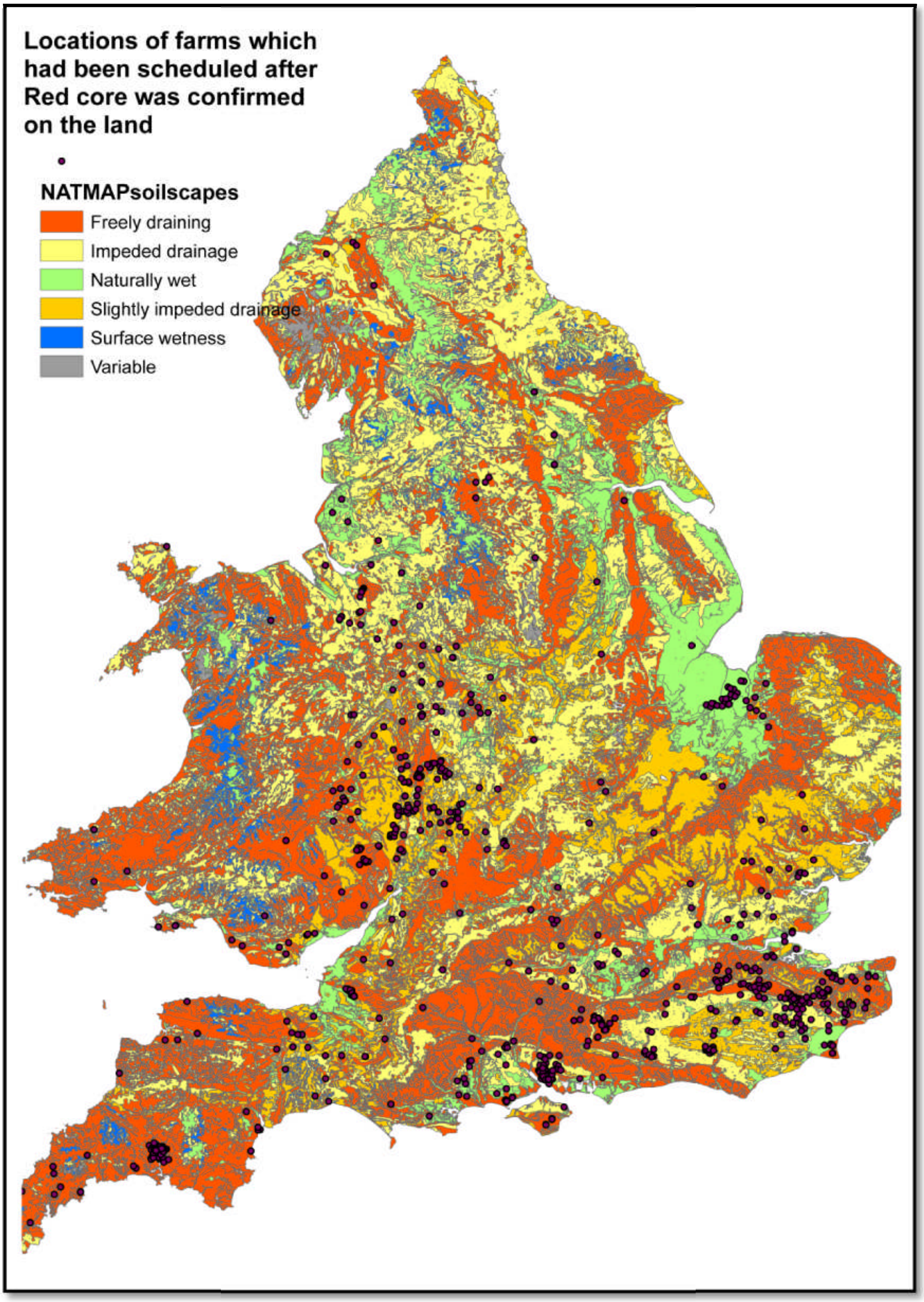


Figure 3-11 Map of England and Wales depicting soil types with 6 different drainage capacities using Soilscapes^{TM}. The map also shows the locations of over 900 outbreaks were land was scheduled after they were found to be infested by Phytophthora fragariae, between 1968 and 2001.

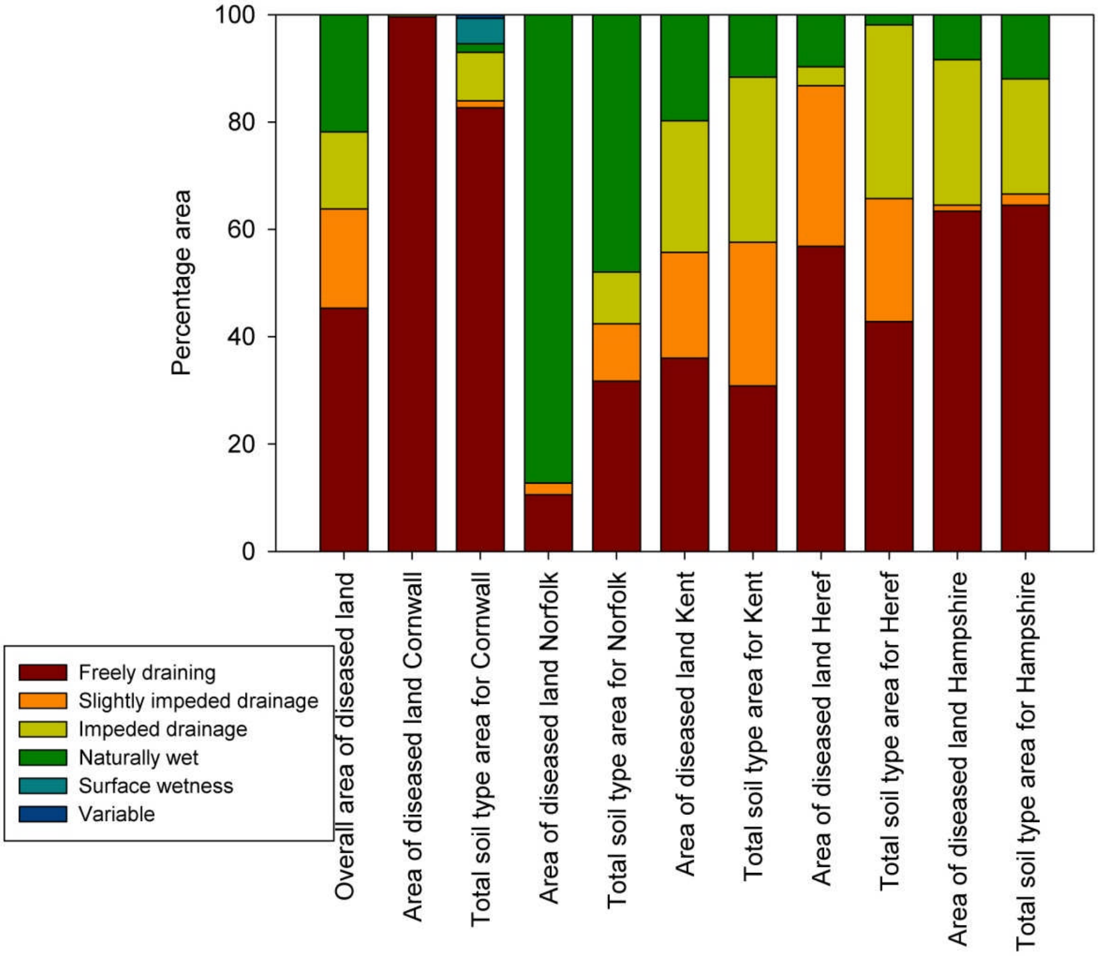


Figure 3-12 Stacked bar chart showing the proportion of the different soil types in infested land, and in the whole county for the 5 counties in which the highest number of cases of scheduled land from P. fragariae infestations was obtained together with the overall total for England and Wales.

On further investigation, it was found that in most cases the size of scheduled land on farms located on naturally wet soils was larger (Figure 3-13). This was also true for the overall England and Wales mean. The only county where this was not the case was Cornwall, since soils of the "naturally wet" category were infrequent there. Instead, most of the infestations in Cornwall took place on freely draining soils (Figure 3-12), even though the size of scheduled land on these types of soils was amongst the smallest for the different soil categories (Figure 3-13). This implies that the drainage capacity of the underlying substrate does have an influence on the severity of red core outbreaks, since a larger area of the crop per farm was affected and subsequently scheduled in soils that were naturally wet (Figure 3-12).

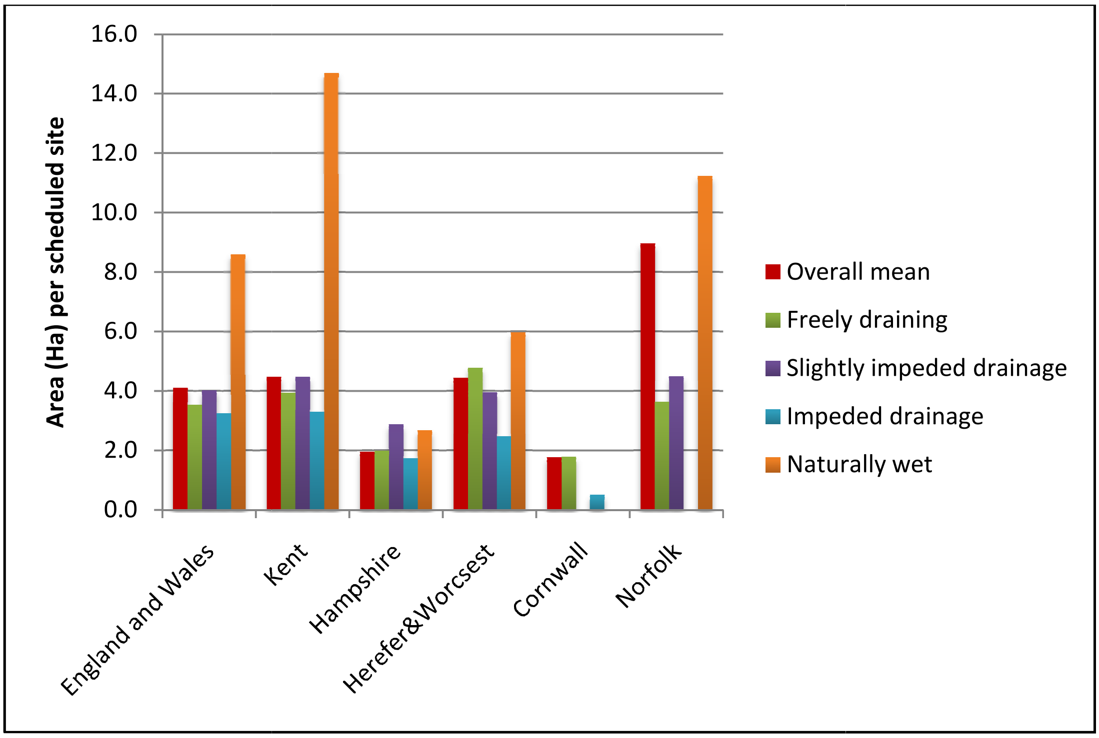


Figure 3-13 Clustered column chart showing the size of scheduled land per site in the different soil types. The soils types are listed in order of draining capacity, from top to bottom (in legend).

In order to investigate the impact of weather on disease outbreaks, the total rainfall and number of days with at least 1mm of rain between October to March were investigated (Table 3-5). It was observed that in one county the mean number of days of rainfall between October and March was in excess of a hundred days, and thus similar to that which Reid (1949) had observed in Scotland. This October to March rainfall in Cornwall could be a factor influencing the high number of actual outbreaks of *P fragariae*in the county, even though most of the soil is of the free draining type. On the other hand, counties that had an October to March rainfall lower than the threshold needed to meet Reid's criteria and still had a higher than expected actual disease incidence, such as in Kent and Hampshire, had slightly higher abundance of soils that had an impeded drainage capacity than the average for the England and Wales, even more so for Kent which had a low level of freely draining soils. This, combined with the size of the industry in Kent, could explain why it had the worst overall record of red core outbreaks in England and Wales. Norfolk, on the other hand, had the lowest October to March rainfall of the five counties and also had a lower than expected actual disease incidence, despite having the highest proportion of naturally wet soils of the five counties. Thus, whilst other factors might be responsible for influencing the low actual disease incidence in

Norfolk, the high proportion of naturally wet soils in the county could explain why the mean infested area in Norfolk was the highest of the five counties.

Table 3-5 List of 5 different counties with the weather variables referred to in Reid (1949) as influencing the incidence of Phytophthora fragaria in western Scotland. The two variables calculated here are the mean October to March rainfall, and mean October to March number of days with at least 1mm of rain for each of the 8 sites. The mean was calculated over the period of 1921 to 2007 and are also accompanied by the standard deviation. The actual and expected disease counts are also given as an indication of the disease intensity in a county.

County	Red core from *Phytophthora fragariae*	October to March rainfall/mm	October to March days of rainfall >= 1mm
Cornwall	159 *(25.6)*	718.6 ± 153.6	101.6 ± 15.8
Hampshire	334 *(106.8)*	438.3 ± 115.2	67.3 ± 12.9
Hereford & Worcestershire	123 *(139.0)*	404.0 ± 101.6	74.2 ± 14.9
Kent	427 *(342.9)*	395.6 ± 100.1	68.2 ± 12.6
Norfolk	70 *(290.9)*	324.4 ± 73.8	68.2 ± 12.6

3.2.3.2.3. Cultivars used and disease susceptibility

In 668 of the outbreaks, the cultivars grown were known. The three cultivars found to be most susceptible to red core were those used before the second World War: Madame Lefevre, Huxley and Royal Sovereign (Table 3-6), being responsible between them for 46% of the records for which cultivars were known. The variety with the fourth highest number of records was Elsanta (7.9% of overall records) which, since the early 1980s, was by far the most common variety used by the strawberry sector (see Figure 2-20).

Table 3-6 The ten cultivars found to have the highest records of infestations of red core between 1920 and 2004

Cultivar	Proportion of known infestations
Madame Lefevre	18.1
Huxley	17.9
Royal Sovereign	10.2
Elsanta	7.9
Cambridge	6.6
Auchincruive Climax	4.6
Hapil	3.9
Cambridge Favourite	3.7
Cambridge Vigour	3.3
Perle de Prague	3.3

3.2.4 Discussion

One of the main outcomes of this study is an understanding of the widespread spatial and temporal variation in disease incidence in strawberries in Great Britain. Whilst temporal variation is already well understood with high and low disease severity years, often depending on the disease epidemiology and effects of weather, spatial variation can often be hard to capture on a national scale. This kind of variation has been observed previously for diseases of wheat throughout the UK (Hardwick *et al.*, 2001). With strawberries, spatial variations in the four studied diseases were found to be independent of the size of the strawberry sector in that region or county, and following spatial statistical analysis carried out on the data, were also found not to be due to chance. Thus other reasons are responsible. The most important of these is probably the weather. Whilst it was not possible to correlate the disease events with prevailing weather events in the counties where disease outbreaks occurred, a lot of epidemiological studies have been carried out on the diseases to establish the effect of weather variables on disease incidence and severity (Xiao *et al.*, 2001, Maas, 1998, Hickman and English, 1951a, Blanco *et al.*, 2004). Prevalent weather patterns in the different counties could affect both crop development and diseases differently. Counties with weather patterns that are more conducive to the development of a certain disease would be expected to have a higher incidence of that disease. For instance, red core is known to be affected by high rainfall and flooding, and could even develop in freely draining soils if the rainfall was high enough (Hickman and English, 1951a), as was found to be the case with the large number of disease infestations of red core in the strawberry sector in Cornwall.

Another factor affecting spatial variation in disease incidence was the soil substrate in which strawberries are grown. This is particularly so for soil borne diseases such as *Phytophthora fragariae* and *Verticillium* wilt. In the former case, higher disease incidence was found even in areas which have a lower rainfall than that described as the ideal amount for the disease to occur (Reid, 1949). In these cases, such as in Kent, the majority of the outbreaks occurred in soils that were not freely draining and, subsequently, were prone to water logging. This created the ideal conditions for red core to develop and in doing so explained why a lower than ideal mean October to March rainfall still ended up with a much higher than expected number of recorded infestations of red core in that county. In fact, the most severe infestations were on soils that were naturally wet, with a much larger area per farm being scheduled, not just in counties with a high number of infestations, but even in counties with a lower than expected number of infestations, such as Norfolk. This clustering of red core infestations had already been observed in the 1940s (Hickman and English, 1951a), although this current study shows it to be statistically significantly on a national level.

The incidence of *Verticillium* wilt, on the other hand, depends on the cultivation history of the field in which the strawberries are being grown. If infestations of *Verticillium dahliae* have previously been recorded in the field, the inocula can lie dormant for up to 25 years (Raffle and O'Neill, 2006) and the quantity of inoculum in the soil could increase as the field is repeatedly cropped with strawberries or another plant susceptible to the disease (Harris and Yang, 1996). This could explain the high number of infestation records in Kent because not only have strawberries been an important crop in the county since the 1920s (Figure 2-3), but so have Hops (Harvey, 1963) which, being susceptible to the same disease (Raffle and O'Neill, 2006), could have led to an increase in inoculum levels of the disease in Kentish soils.

The use of susceptible cultivars in the past (Ellis, 1970) has also influenced the incidence of disease in the strawberry sector. In all four diseases, the two cultivars with the highest record of disease incidences were pre-Second World War cultivars, in a time when developing disease resistance was not yet well understood (Harris *et al.*, 1934). In fact, the cultivars were so susceptible to *P. fragariae* in particular that it is reported that there was "devastation en masse" of strawberry beds in the affected areas (Wardlaw, 1927). In an experiment carried out by Hickman and English (1951b), the cultivars Madame Lefevre and Huxley's Giant were found to be the two varieties most susceptible to *P. fragariae*. In the disease datasets collected through this study, these two cultivars also had the highest records of red core infestations over the 90 year period, even though they went out of use by the early 1960s. Conversely, Cambridge Favourite, which was the most popular cultivar in the 1960s and 1970s, obtained relatively few records of disease infestations in this study, being ranked eighth and responsible for only 3.7% of the infestations where the cultivar was known. This could be attributed to its partial resistance to *P fragariae* (Gooding, 1972, van de Weg *et al.*, 1989) which was thought to be derived from its tolerance to drought, thus compensating for the loss of roots through disease infestation. In comparison, twice the number of disease incidence records were obtained for Elsanta, which was the most common variety grown since the early 1980s. This lies in its susceptibility to the pathogen (Perry and Raffle, 2004). The same could be said for Verticillium wilt, the other soil borne disease covered by this study. In Keyworth and Bennett (1951), Huxley's Giant and Madame Lefevre were considered as severely susceptible to the disease, whilst Cambridge Vigour was described as very highly susceptible (Talboys and Bennett, 1969) and through this study these three cultivars obtained three of the four highest records of infestations from Verticillium wilt. Notwithstanding the improvement in disease resistance in strawberry cultivars today (Shaw *et al.*, 2010), the disease still remains one of the most devastating of all soil-borne strawberry diseases in the UK (Raffle and O'Neill, 2006, Lole *et al.*, 2009). In view of this, more growers have been raising their crops out of the ground into soil-less substrates which are free of soil borne diseases (Lieten *et al.*, 2004).

Powdery mildew and grey mould have been amongst the two most common diseases in England and Wales since the 1920s (MAFF, 1922, British Mycological Society, 1929, Dennis and Foister, 1942, Baker, 1972, Garthwaite *et al.*, 2006) and have been continuously recorded in the datasets studied. Since the mid 1960s, over 80% of fungicides used on strawberries were targeted at these two diseases (Sly, 1975, Steed *et al.*, 1978, Sly, 1982, Wilder, 1987, Davis *et al.*, 1992, Garthwaite and Thomas, 1996, Woods, 1999, Garthwaite and Thomas, 2000, Garthwaite and Thomas, 2003, Garthwaite *et al.*, 2006). Until the late 1990s, a greater proportion of fungicides were used to combat *B. cinerea*. This changed after 2001 with the increased use of protected cultivation (2006, Garthwaite *et al.*, 2009), when *P. aphanis* became the pathogen against which most spray applications were made. This impact of protection on powdery mildew in strawberries could be seen in the datasets whereby the majority of disease records where protected methods were used were attributable to this pathogen. The impact of this cultivation practice on powdery mildew in strawberries has been known for a few decades (Jordan and Hunter, 1972), as protected cultivation is known to favour the development of *P. aphanis* and reduce the incidence of *B. cinerea* (Xiao *et al.*, 2001). This increased use of protection by the UK strawberry industry in the last decade (refer to Figure 2-22) has led to the replacement of *B. cinerea* by *P. aphanis* as the most common and sprayed against disease in strawberries in the UK.

The use of long term, national disease datasets like these can be useful in providing the opportunity to study the development and influence of plant diseases on a sector during a relatively long time scale. Nevertheless, there are limitations in the data in terms of content and their reliability. For instance, data might not be available on all of the variables for each record, such as the production methods and cultivars used. Moreover, one cannot assume that this is a comprehensive list and that every single outbreak in each farm in England or Wales since 1920 is actually recorded in these datasets. There inevitably will be disease outbreaks that were not reported to the authorities, and reports might also depend on the consistency in the reporting of disease outbreaks by regional inspectors. These reasons, together with the lack of an exact date for the disease outbreaks, have made it impossible to link the disease outbreaks to obvious, real-time historic weather events. In fact statistical analysis used to correlate disease presence or absence during a year with over 2500 potential weather predictor combinations was done to determine which weather events were responsible for the disease events. These proved futile as no solid correlations were obtained, and eventually had to be left out of this study.

Despite these limitations, the records do provide much useful data and long term trends, showing spatial clustering in plant disease. The data also provides evidence for disease being a driver of change in the strawberry sector, such as the development of disease resistance in strawberries since the 1940s. More detailed records were available for *P. fragariae,* which were collected from 1946 to 1995. These years correspond to when legislation was introduced to prevent the spread of this disease (1946), and the disease became notifiable by law (1952) requiring registration. By 1993 registration was no longer required except in nurseries selling runners with plant passports. Some of the best data for this disease were from this period since it was more likely that an infestation was recorded as there was a legal obligation to do so. Nonetheless, there is evidence that the rest of the datasets for the other three diseases and for the earlier records of red core are reliable. Firstly, the earliest records of the diseases encountered in these datasets were similar to that found in the literature, such as the first records of red core and *Verticillium* wilt in 1920 and 1933 respectively in these datasets being around the same time as those in published literature (MAFF, 1922, Keyworth and Bennett, 1951).

Secondly, evidence for events that are mentioned in the literature such as the unhealthy plant stock and cultivars that led to a decline in the strawberry sector between 1920 and the second World War (Ellis, 1970), is also evident in these datasets; the three most popular varieties in that phase were responsible for just under half of the total records for which cultivars were known and taken over the 90 years covered by the study. Moreover, evidence of the movement of infected plant material through trade, in particular through a major outbreak of Verticillium wilt in several nurseries after the second World War (Hickman and English, 1951a, Keyworth and Bennett, 1951), is seen in the disease datasets through a drastic increase in nationwide Verticillium records post World War Two (see Figure 3-1). Thirdly, whilst it was known in the industry that certain diseases were more severe in certain areas (Baker, 1972), this study has shown evidence of spatial variation on a national scale in England and Wales.

3.3. PHYTOSANITARY CONTROLS AS AN EFFECTIVE MEANS OF CONTROLLING PLANT DISEASE: A CASE STUDY OF *COLLETOTRICHUM ACUTATUM* AND THE UK STRAWBERRY INDUSTRY

3.3.1 Introduction

3.3.1.1. Phytosanitary control of plant disease

In the last 4 decades between 1970 and 2004, 234 pathogens were recorded for the first time in Great Britain (Jones and Baker, 2007). Although some of these pathogens may have arrived by natural means, the authors of that study suspected that most were introduced with imported plant material, such as seedlings, plants, budwood, rootstocks, bulbs, corms and tubers. Whilst movement of pathogens across borders can occur by natural means, the existence of trade routes facilitates the movement of plants and the establishment of pests or pathogens that might accompany them (Ebbels, 2003).

The solution to limit the risk of alien pathogen entry, using measures that would not hinder trade, is nowadays widely accepted to be the use of phytosanitary legislation to control the movement of plant material. As of the end of October 2010, 177 countries were signatories to The International Plant Protection Convention, which is an international plant health agreement that aims to protect cultivated and wild plants by preventing the introduction and spread of pests.

Phytosanitary control of plant pests has existed at an international and national (UK) level for a number of centuries (MacLeod *et al.*, 2010). In Great Britain, the foundations of a Phytosanitary system were set up in 1877 with the introduction of the Destructive Insects Act, later followed by the Destructive Insects and Pests Act in 1907 (Dehnen-Schmutz *et al.*, 2010). These acts introduced the inspection and notification system, and for the first time introduced a list of quarantine species and gave the power to the authorities to destroy infested crops (Ebbels, 2003). The Plant

Health Act of 1967 later replaced these two acts to favour a managed risk based approach, whereby controls would ensure a sufficient level of protection without hindering trade (MacLeod *et al.*, 2010). This meant that a subset of the plants or plant material entering the country would be inspected, based on a risk assessment depending on the species and the country of origin. Notwithstanding the risk to biosecurity, until gaining EU membership, Great Britain maintained a privileged position as an island and thus was better able to control its imports (Brasier, 2008). EU membership brought the single market concept which meant that once plant material had been cleared through any external EU border, it would be able to move freely within the European Union (MacLeod *et al.*, 2010). The consolidation of EU plant health legislation in 1993 facilitated this by introducing the "Plant Passporting" system, whereby propagators intending to export plant propagation material to other EU states would need to satisfy a number of plant health requirements, thus enabling their certified plant material free movement through the EU (MacLeod *et al.*, 2010). Despite these measures, many plant pathogens still make it through border inspection posts undetected. In a study by Jones and Baker (2007), the introduction into Great Britain of some important pathogens was traced to the importation of crops that were supposed to have plant passports. Moreover, the same study identified that, when records were available, 47% of the introductions were traced back to plants originating in The Netherlands.

Thus, whilst phytosanitary control is a tool in reducing the risk of importing alien pathogens, it still has its weaknesses. Control is usually done through visual checks and, where reasonable doubts exists regarding the health status of the plant, samples can be taken for laboratory analysis (OEPP/EPPO, 2008b). Diseases that do not show any visible signs of infection or have a latent phase often pass through the borders undetected (Brasier, 2008). Nevertheless, some suggest that, while the risk of introductions exist, for a phytosanitary system to be effective, it should be assessed by its ability to reduce the expected probability of successful invasion rather than the certainty of preventing it (Mumford, 2002). Others have gone as far as suggesting a substantial reduction in the international trade of plants as the best means of reducing threats from alien pests (Brasier, 2008). Mwebaze *et al.* (2010), on the other hand, suggest focusing phytosanitary inspections on plants originating from countries that provide a higher risk and have an established track record of exporting infested plant material.

The value of plant imports into the UK have increased, from around £370 million in 1992 to around £900 million fifteen years later, with around 31% of this value based on rooted plants (Brasier, 2008). Whilst some would suggest that increasing the volume of trade could lead to an exponential increase in the number of alien fungi (Desprez-Loustau *et al.*, 2010), Jones and Baker have found that, although trade volumes in live plants in the UK have actually increased, this was not followed by a similar increase in the rate of entry of alien pathogens over the same time period (2007). The authors of that same study suggest that imports may have become healthier or alternatively, entry inspection procedures into the UK are becoming more effective or there may be a combination of both possibilities.

3.3.1.2. Strawberry black spot – *Colletotrichum acutatum*

Colletotrichum acutatum is a common fungal pathogen of a wide range of crops and wild plant species. It is distributed throughout the world and causes extensive crop losses every year (Peres *et al.*, 2005) being considered the second most important pathogen after *Botrytis cinerea* (OEPP/EPPO, 2003). It causes necroses and blights in warm weather (Maas, 1998) on tissues such as leaves, petioles, flowers, fruit, or even roots on a wide range of hosts. (Peres *et al.*, 2005). In strawberries, *C. acutatum* primarily acts as a necrotroph on strawberry tissues (Curry *et al.*, 2002), affecting the flowers, fruit, leaf and petiole tissue and causing strawberry black spot disease. It can also produce root necrosis, which most probably occurs through the contamination of roots of transplants during digging, trimming and packing operations in the nursery (Peres *et al.*, 2005).

The conidia of *C. acutatum* are usually produced in acervuli on host tissue (Peres *et al.*, 2005) and are mainly dispersed through rain-splash dispersal, which is proportional to the rain intensity and size of the rain drops (Madden *et al.*, 1996, Ntahimpera *et al.*, 1999).

3.3.1.2.1. Epidemiology and disease incidence

C. acutatum may overwinter as mycelium and/or appressoria in or on different parts of the host (Wharton and Diéguez-Uribeondo, 2004). In a study by Ureña-Padilla *et* *al.* (2001), inoculum of *Colletotrichum* was found not to survive in buried plant debris between seasons. Moreover, the pathogen is capable of colonizing weeds surrounding the strawberry fields and could survive for 3 months on other crops such as tomato, pepper and eggplant leaves (Freeman *et al.*, 2001). Thus overwintering of the pathogen could also be due to its spread from strawberry plants to weeds adjacent to strawberry fields and then re-infesting new strawberry fields the following year (Peres *et al.*, 2005).

Infection of new strawberry plants in a previously uninfected field usually occurs through the introduction of diseased plants from nurseries. Whilst the plants may be symptomatic, the pathogen might be introduced on asymptomatic leaves or petioles, presumably as appressoria and quiescent infections (Peres *et al.*, 2005). According to Simpson *et al.* (1994), *C. acutatum* on strawberry was introduced for the first time in the UK on strawberry runners of cultivar Brighton, which were imported from California in 1983. As indicated by the same authors, phytosanitary precautions had until the early 1990s been successful in controlling the disease. Nevertheless, a later study by Simpson *et al.* (2006) showed evidence of considerable differences in pathogenicity among several UK isolates of *C. acutatum* that suggested the presence of a heterogeneous population of the pathogen in the UK. The authors go on to suggest that this would have most likely resulted from the multiple introductions of infected plant material through imports from abroad.

3.3.1.2.2. Phytosanitary control of strawberry black spot in Europe

Phytosanitary control of *C. acutatum* is limited due to the difficulty in detecting the disease reliably through visual inspection. The phytosanitary procedures of the European Plant Protection Organisation recommend laboratory testing to detect any latent infection. They also suggest that “for Colletotrichum acutatum at least one plant should be sampled per 1000 plants with a minimum of 50 plants for small lots and a maximum of 300 plants taken from different parts of the lot” (OEPP/EPPO, 2008b).

C. acutatum was first listed in European legislation through Commission Directive 92/103/EEC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the

Community (Anonymous, 1992). It was listed in Annex I Section 2, as a harmful organism whose "introduction into, and spread within, all member states shall be banned." Fifteen years later, following a Pest Risk Analysis (PRA) initiated by France and complemented by a survey among the Member States, *C. acutatum* was deregulated as a harmful organism for the European Union (De Hoop *et al.*, 2008). The decision was taken by the member states following evidence that the disease had become widespread within the Community (Anonymous, 2008).

Notwithstanding the declassification of *C. acutatum* as a quarantine organism, the EPPO certification scheme requires that plants recommended for certification as Nuclear stock or Propagation stock I should be free of the disease (OEPP/EPPO, 2008a).

3.3.2 Materials and methods

In this chapter, the dataset for *C. acutatum* was used to assess the effectiveness of UK Phytosanitary legislation to halt the entry of quarantine disease into the UK. These datasets were obtained from computer based databases held by the authorities responsible from Plant Health during the 1980s and 1990s. The database was called *Pathdiary* and it was kept between 1984 and 2002. It was collected by the Ministry of Agriculture, Fisheries and Food in the 1980s at the Harpenden Laboratory and later at the Central Science Laboratories in York. In it were recorded the outbreaks of quarantine diseases in the UK between 1983 and 2002. In all, 479 entries were recorded consisting almost entirely of records of two phytosanitary diseases: *Phytophthora fragariae* and *C. acutatum.* Each record included the date the entry was made, the farm location (through an address or name of farm or farmer), the disease and cultivar name of the strawberry plants affected. On other occasions, there was also a reference to the cultivation method, infection level and action taken by the Plant Health and Seed Inspectors. In almost all cases, the farm was identified and a post code obtained indicating the exact location of the outbreak. The records of infected plant material often involved cases where plants had been imported from abroad. These consisted of infected material stopped at the National point of entry and at border inspection posts (BIPs). In all cases, the country from which the samples originated was also listed.

The incidences of disease were all positive records following diagnostic tests taken by Plant Health and Seed Inspectors in their surveillance work on quarantine disease. Samples were taken when disease symptoms were encountered or when plants were suspected of having the disease. The disease was then confirmed by the Central Science Laboratories following laboratory analysis.

Using the farm name, or farmer's name, the farm was located for the purposes of this project, and a post-code obtained for all of the incidences, indicating the exact location of the outbreak. These were then used to plot the disease outbreaks spatially using ArcGIS 9 (ArcMap 9.2)(ArcGIS, 2009).

For simplicity, the results are analysed into three parts as follows:

- Sections 3.3.3.1 to 3.3.3.5 - records of outbreaks of *C. acutatum* are grouped into five time-series and analysed to study the development of the disease in the UK from 1982 to 2008,
- Section 3.3.3.6 - the role of imports and trade on the establishment of the disease in the UK is analysed,
- Section 3.3.3.7 - the geographic distribution of outbreaks of *C. acutatum* in the UK is then analysed.

3.3.3 Results

3.3.3.1. First phase – Entry into the UK (1982-1987)

3.3.3.1.1. First entry

The first incidence of *C. acutatum* in the UK, recorded in the database Pathdiary, occurred in 1982 on plants of the variety ‘Hekker’. The plants were imported from the USA by a plant nursery (here referred to as Importer A) in the autumn of 1982, to be used in trials. They were planted in the ground, on land belonging to the importer in Kent, but following scientific advice from Harpenden Laboratories (MAFF), the plants were destroyed. The record in Pathdiary was made on 26 April 1984, and it is assumed that some time might have passed between the planting of the diseased plants in the soil and their discovery and destruction.

3.3.3.1.2. Spread to other farms in the first five years

In 1983 the first record occurred in the UK of *C. acutatum* being spread between farms. The disease occurred on a farm in Cornwall, on plants of cv. Brighton bought from the same nursery which had been found to be infected in 1982. The disease was recorded on the same Cornish farm each year from 1984 to 1987 on three more varieties obtained from Importer A, i.e. cvs Bogota, Red Gauntlet and Rapella.

In 1985, another farm recorded an outbreak on runners of cv Hekker obtained from a producer in Spain. These plants had been imported without a phytosanitary certificate.

By 1987 a total of 10 outbreaks of *C. acutatum* were recorded in the UK, two of which were from direct imports. Apart from these, there were another 7 intercepted imports of runners or fruits that were found to contain *C. acutatum* (see Table 3-7) and were stopped at the border inspection posts, by either having the material destroyed or, in case of fruit, they were destined for consumption in the UK market.

From records in Pathdiary, it was observed that during these first five years, only in two instances was there a recommendation for any action to be taken to stop the spread of the disease once it was detected in a farm. Both involved the imported diseased material from abroad. Although the Cornish farm that had 8 incidences was monitored on an annual basis, there was no record of any action taken to curtail the disease.

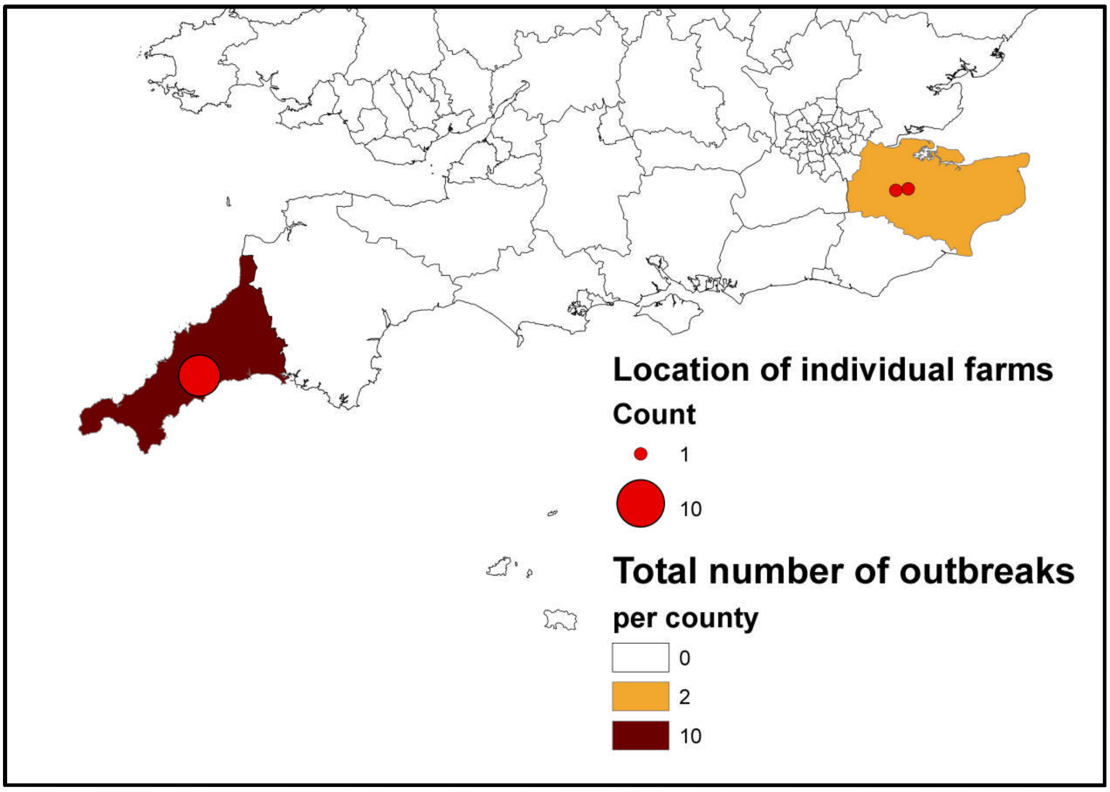


Figure 3-14 Colletotrichum acutatum outbreaks in the first five years following its introduction in the UK in 1982

Table 3-7 Records of incidences of Colletotrichum acutatum on farms during 1982-1987, and the number of cases of intercepted plant material found at border inspection posts during the same period.

Year	Diseased material that was intercepted at the border inspection posts	Diseased material that was not intercepted	Records of *C. acutatum* on farms
1982		1	1
1983			1
1984			1
1985	3	1	4
1986	2		1
1987	2		2
Total	7	2	10

C. acutatum was first listed in UK legislation at the end of this phase, in The Plant Health (Great Britain) Order 1987. In this order, the import of diseased plants or fruit from third countries was forbidden. Moreover, plants from third countries were required to be accompanied by a certificate declaring that they were not grown in a field that was infected with *C. acutatum* or within 50m from such a field. Notwithstanding this, PHSI had the power through existing legislation to order the destruction of plant material if they had serious concerns that they could pose a phytosanitary risk.

3.3.3.2. Second phase – Establishment and spread of the disease (1988-1992)

The second five-year phase saw the spread of the disease throughout England. Fifty one records of *C. acutatum* were reported, of which 33 were from imported plant material that failed to be intercepted at the BIPs (Table 3-8). A total of 29 new farms were involved and the disease now had spread to 14 different counties, 12 of which being first records in that county. Another 35 cases of infected plant material were recorded as being intercepted at the BIPs resulting in recommendations that the material be destroyed or re-exported.

Table 3-8 Colletotrichum acutatum incidences and interceptions between 1988-1992

Year	Diseased material that was intercepted at the border inspection posts	Diseased material that was not intercepted	Records of *C. acutatum* in farms
1988	7	11	15
1989	7	8	14
1990	5	6	14
1991	13	1	1
1992	3	7	7
Total	35	33	51

Whereas material intercepted during importation, was ordered for destruction or re-exportation, only three eradication notices were served for the cases involving incidences on the farms. In two of these cases, it was recommended that the grower would not plant strawberries in the infected field, whereas in the third the PHSI recommended the destruction of the plants.

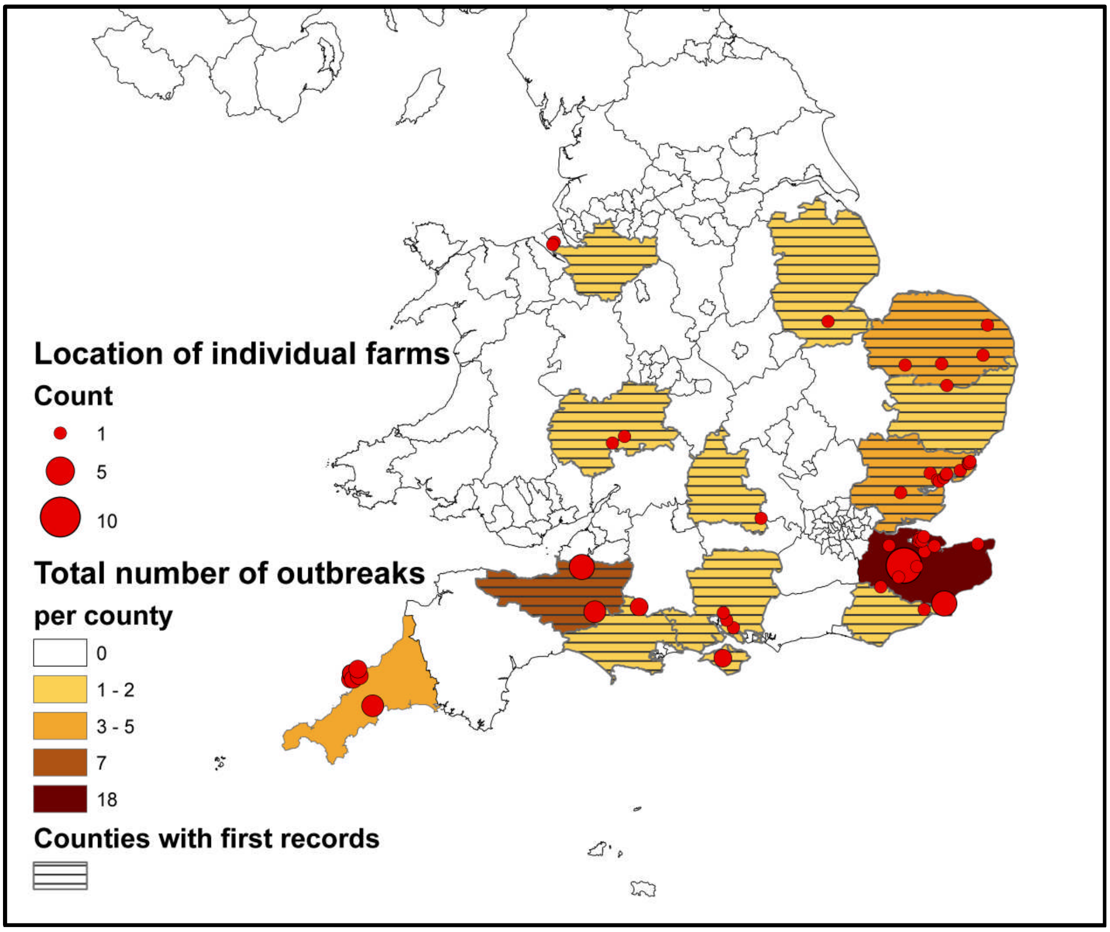


Figure 3-15 Colletotrichum acutatum outbreaks in England between 1988 and 1992. The counties which are recoding their first outbreaks of the disease are shaded in horizontal lines.

In 1990, the introduction of The Plant Health (Great Britain) (Amendment) Order 1990 included *C. acutatum* in Schedule I, forbidding its entry into the UK on imported plant material, including from the EU. It also made illegal the cultivation and sale of strawberry plants infected with *C. acutatum* within the UK, and obliged growers having their land infected by the disease to inform the relevant authorities.

3.3.3.3. Third phase (1993-1997)

The Plant Health (Great Britain) Order of 1993 declared *C. acutatum* a “notifiable”, disease, meaning that land known to be infected with *C. acutatum* now had to be notified to the PHSI.

In this third five-year phase, the disease spread to another 6 counties within England. A total of 39 further cases of *C. acutatum* were reported in 15 different counties (Figure 3-16). The majority of cases were found on new farms (26 new farms) encountered during the Strawberry black spot (SBS) survey (carried out in 1995 by the PHSI). Of the 39 cases, only 9 were traced back to imported material. Another 10 cases of infected plant material were intercepted at the BIPs where once again plant material destruction or re-export was recommended.

Table 3-9 Colletotrichum acutatum incidences and interception between 1993-1997

Year	Diseased material that was intercepted at the border inspection posts	Diseased material not intercepted	Records of *C. acutatum* in farms
1993	6	3	6
1994	1		1
1995	1	4	25
1996	2	2	4
1997			3
Total	10	9	39

During this phase, more direct action was taken on behalf of the authorities to curtail the spread of the disease and in most cases the destruction of the beds was recommended. However, from 1996 onwards, no further requests for destruction were made due to an apparent new “relaxed” policy that now focussed on monitoring rather than eradication. A list of infected farms was still kept and those nurseries found to have incidences of *C. acutatum* were taken off the Plant Health Propagation Scheme (PHPS). These nurseries were however allowed to sell non-PHPS material to farms already infected by the disease.

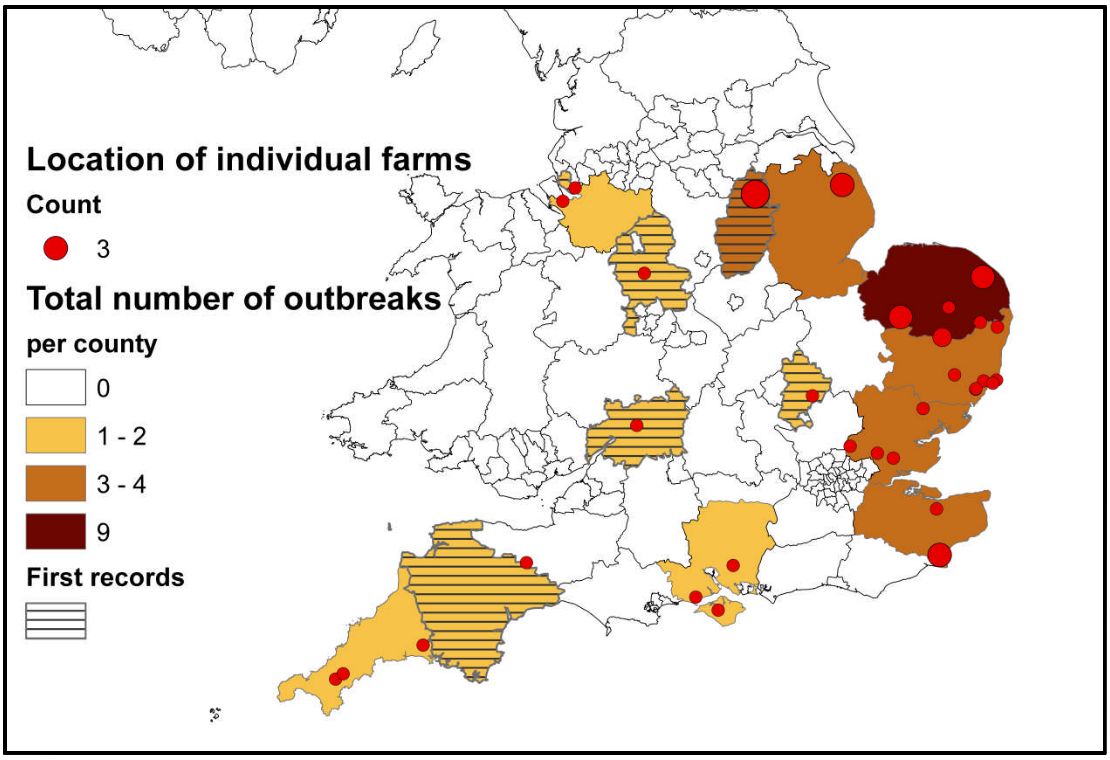


Figure 3-16 Colletotrichum acutatum outbreaks in England between 1993 and 1997. The counties which are recoding their first outbreaks of the disease are shaded in horizontal lines.

3.3.3.4. Fourth phase (1998-2002)

The fourth five-year phase saw the disease spread to another 7 new counties within the UK, two of which were in Scotland and another on Jersey. A total of 56 cases of *C. acutatum* were reported in 16 different counties. Half of the cases were found on new farms (28), most of which were encountered during a country-wide survey carried out in 1999 by the PHSI. This was done following an outbreak found on PHPS material of cv Everest in a major strawberry nursery. The PHSI then inspected all farms that had been supplied by this nursery. Not surprisingly, of the 30 cases recorded that year of having *C. acutatum*, 21 were on plants of cv. Everest, even though the most common variety cultivated at that time was cv. Elsanta. Of the 56 cases, only 9 were traced back to imported material (Table 3-10). This is clear evidence that the disease had become well established in the UK by this stage. Only 3 cases of infected plant material were intercepted at the BIPs. As in previous phases, plant material destruction or re-export was recommended.

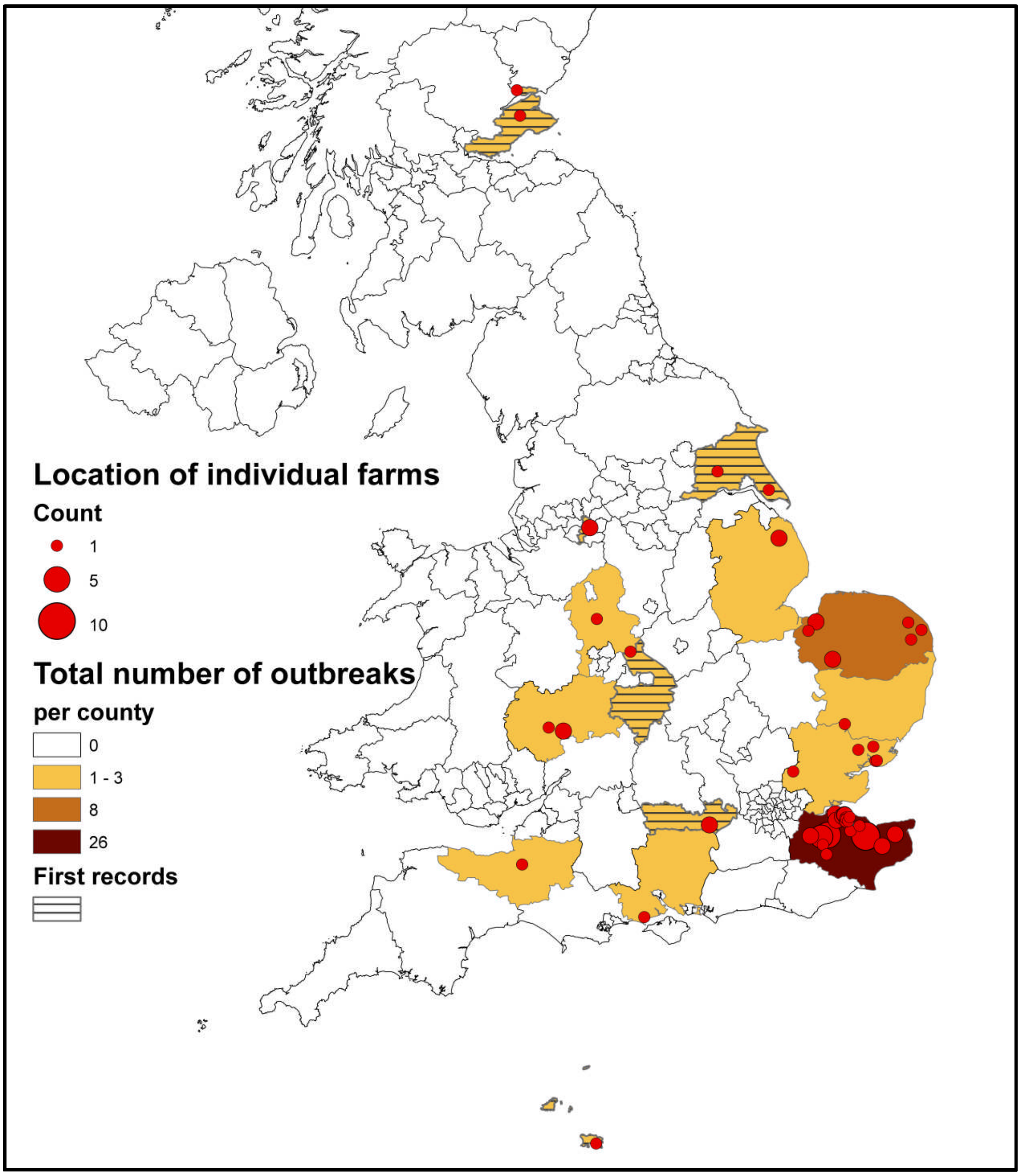


Figure 3-17 Colletotrichum acutatum outbreaks in England between 1998 and 2002. The counties that are shaded in horizontal lines did not have Colletotrichum acutatum recorded previously.

Table 3-10 Colletotrichum acutatum incidences and interception between 1998 and 2002

Year	Diseased material that was intercepted at the border inspection posts	Diseased material that was not intercepted	Records of *C. acutatum* in farms
1998	0	1	4
1999	0	5	30
2000	1	0	8
2001	1	2	7
2002	1	1	7
Total	3	9	56

3.3.3.5. Fifth phase – till removal from quarantine list (2003-2008)

The fifth five-year phase saw the least number of recorded incidences of *C. acutatum* since it became established. In the meantime, the Plant Health Orders of 2005 for England and Scotland and The Plant Health (Wales) Order of 2006 reconfirmed a ban on the import and sale of plants infected with *C. acutatum*, and declared the disease notifiable only in nurseries.

Table 3-11 Colletotrichum acutatum incidences and interception between 2002 and 2007

Year	Diseased material that was intercepted at the border inspection posts	Diseased material that was not intercepted	Records of *C. acutatum* in farms
2003	1	1	3
2004			1
2005	1	1	3
2006			0
2007			0
Total	2	2	7

The disease ceased being considered as a quarantine organism on 30 September 2008, after it was removed from the list of harmful organisms, following introduction of Commission Directive 2008/64/EC (Anonymous, 2008). The Plant Health (England) (Amendment) Order 2008 consequently adopted this directive and declassified *C. acutatum* in England. Wales and Scotland adopted similar measures in the same year. Following this, records of *C. acutatum* were only kept for tests carried out by the Central Science Laboratories (now FERA) on samples sent to them for testing by the public.

3.3.3.6. Entry into the UK and establishment of the disease

When studying the data obtained from these databases, it was found that 68% of the outbreaks were trade-related (112 out of 164 cases). Of the trade-related cases, half could be traced back to an import (56 cases), while the rest were acquisitions made from a nursery that was already found to have infected plant material (Figure 3-18).

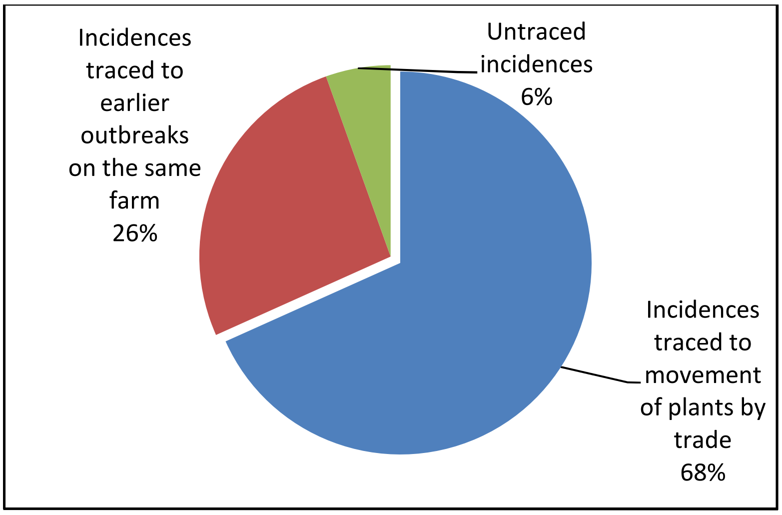


Figure 3-18 Pie chart showing the causes of the 164 recorded incidences of strawberry black spot outbreaks in the UK attributed to C. acutatum between 1982 and 2007

Of the non-trade-related cases, 43 were farms having the second or repeated outbreak. Only 9 of the recorded outbreaks, or 5.5%, could not be traced to a trade related case or explained by a previous outbreak on the same land. In the meantime, a total of 57 cases of plant material were stopped at the BIPs between 1982 and 2007. Of the 56 cases where plant material infected with *C. acutatum* passed undetected at the BIPs and found their way to the field, most occurred between 1988 and 1993 (Figure 3-19).

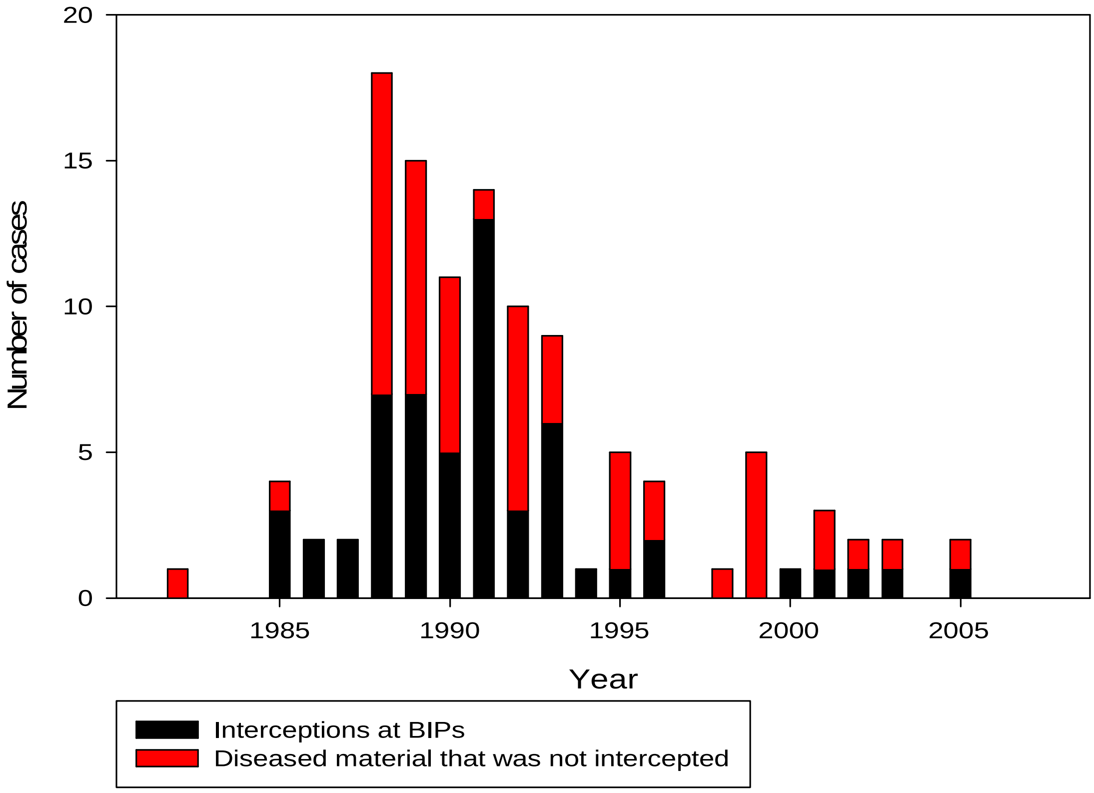


Figure 3-19 Annual records of interceptions at the BIPs and cases when infected plants were not intercepted and ended up being planted in the field.

In Figure 3-20, the three major peaks in annual disease incidence (green line) show that the largest records of disease were accompanied by a spread of *C. acutatum* onto new farms (steeper increase in farmers involved to date). The three peaks in strawberry black spot incidence correspond to the following events:

- The first, between 1988 and 1993, can be attributed to repeated imports of infected material during that same time period (compared with same period in Figure 3-19).
- The peak in records in 1995 is attributed to the Strawberry Black Spot survey carried out by the PHSI that same year.
- The peak in 1999 was due to another investigation carried out by the PHSI.

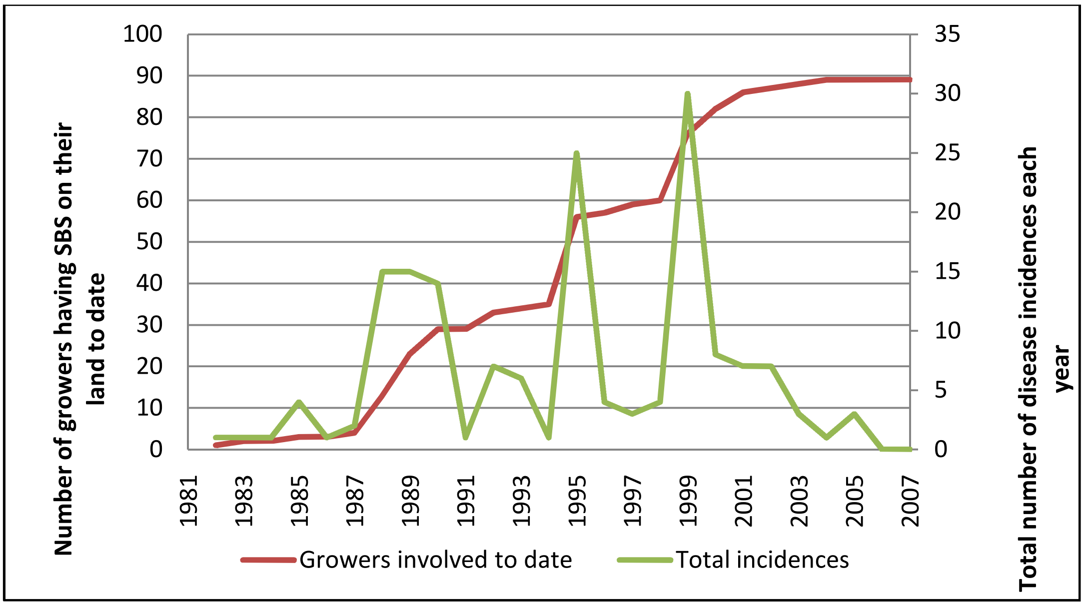


Figure 3-20 *The annual records of disease incidence in UK farms (green line) plotted against the accumulated no of growers having C. acutatum in their land to date (red line).*

When investigating how many importers were actually responsible for the entry of diseased plant material into the UK, it was found that 60% of the cases were attributed to two importers (Figure 3-21). Moreover, of the 56 cases of imported diseased plant material, 42 originated from other EU countries, 25 of which were from the Netherlands (Figure 3-22), which was the most important source of strawberry runners infected with *C. acutatum*.

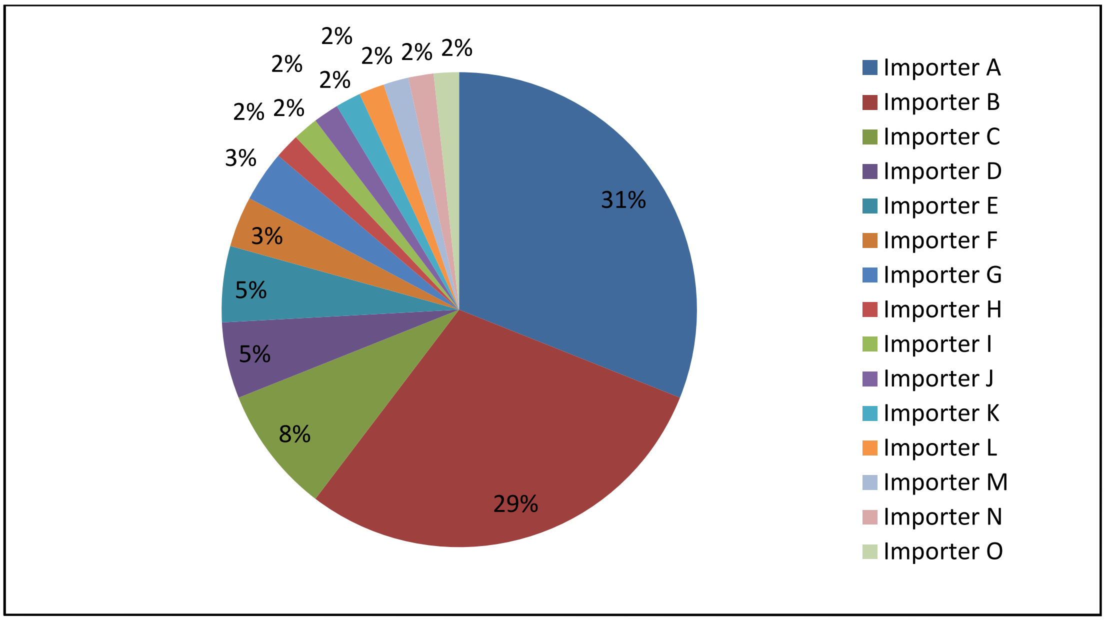


Figure 3-21 *Pie chart showing the imports of diseased plant material being attributed to 15 different importers.*

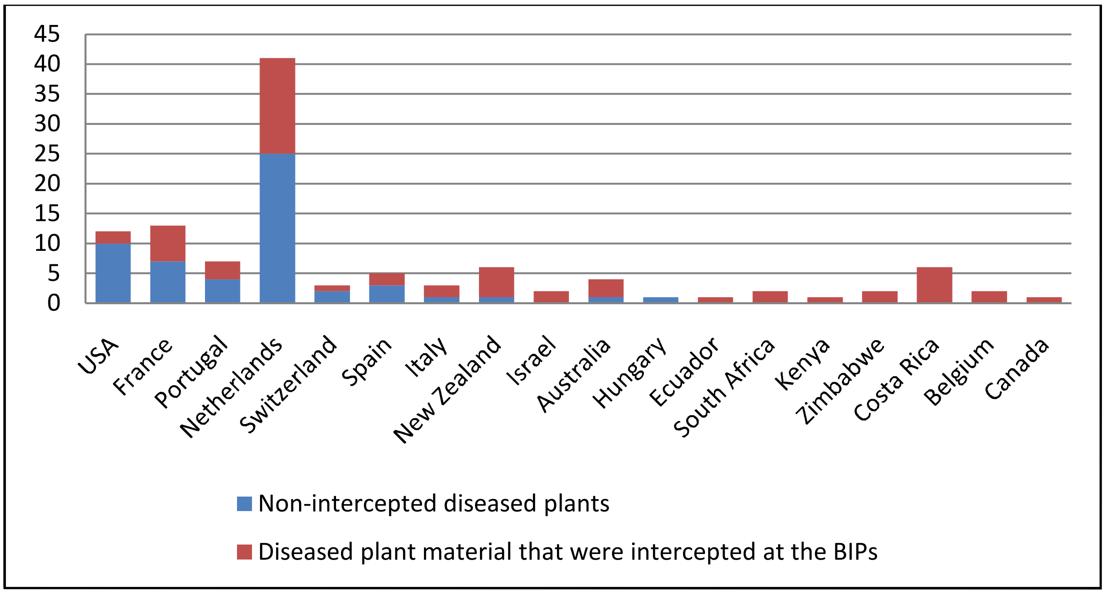


Figure 3-22 Stacked column chart showing the imports of diseased plant material recorded in the Pathdiary database. These included both interceptions of diseased material at the BIPs which were subsequently destroyed, and also non-intercepted imported infected material.

3.3.3.7. Distribution of *C. acutatum* throughout the UK

The density of occurrences of *C. acutatum* outbreaks over the 25-year period since its entry into the UK follows closely the major areas of cultivation of strawberries (Figure 3-23). Kent, being the most important county for strawberry production in England during the 1980s and 1990s, contributing around 20% of crop area at the time, had the largest number of farms having infected material, and the largest number of nurseries having imported the disease. In fact, 5 of the 14 nurseries involved were based in Kent; between them, they were responsible for 42 of the 56 cases (75%) involving import of plant material infected with *C. acutatum*.

Although Kent showed a relationship between the crop area and the number of outbreaks of *C. acutatum*, the same did not apply to a number of other counties in the UK. Apart from low level incidence in Fife and Dundee in Scotland, the disease seems to be absent north of the East-riding of Yorkshire, even though strawberries are grown in these counties. Similarly, no disease was encountered in Wales and although Cornwall was not one of the main counties for strawberry cultivation, it had one of the highest incidences of the disease in the UK. It is also the county where the farm having the largest number of records is located.

Figure 3-23 Maps showing: (left) the proportion of the total UK strawberry industry by county between 1982-2007 (different shades of pink) and the location of farms with outbreaks of C. acutatum during the same time period (size of green circle indicates no. of outbreaks on same farm); (right) number of outbreaks per county (different shades of grey), together with the number of nurseries per county involved in the importation of plant material infected with C. acutatum during 1982-2007 (red triangle).

3.3.4 Discussion

Through this study, the first record of *C. acutatum* on strawberries in the UK was found to occur in the autumn of 1982, when diseased plants of the cultivar Hekker were imported from the USA and planted by an importer based in Kent. This is a year earlier than the first UK record of 1983 reported by Simpson *et al.* (1994). It also precedes the first record of the disease in strawberry in the USA by a year (Smith and Black, 1986), even though the diseased plants recorded in Kent in 1982 were found to have originated from the USA itself.

More importantly, this study established that there were at least 56 known recorded cases of imports of infested plant material that were not intercepted by BIPs , and were subsequently planted in the field. This supports the proposition (Simpson *et al.*, 2006) that the heterogeneous nature of the pathogen in the UK, was likely to have resulted from multiple introductions of infected plant material. It also suggests inadequacies in the phytosanitary controls in place at the time which failed to prevent entry of pathogens that have quiescent phases, and can pass undetected through the preliminary visual inspections (Brasier, 2008). In fact, were it not due to the repeated entry of the pathogen through imports, the disease might not have become established at all. In addition, two thirds of the recorded incidences were traced back to internal UK trade, suggesting that trade transmission was highly influential in the successful spread of the disease.

The source of the infected imports also demonstrates the weaknesses of the EU phytosanitary system. The fact that 42 of the 56 cases of infected plant material were from other EU countries suggests that plant passporting was not effective as a barrier to the spread of pathogens across national borders within the EU or alternatively, propagators in the EU were repeatedly selling infected certified plant material, or there may be a combination of both. Moreover, the majority of the cases of infected plant material from EU sources were from The Netherlands. This is similar to what Jones and Baker found in their study, where 47% of the introductions of alien pathogens whose source was known were from the Netherlands (2007). On the other hand, the Netherlands was also the biggest known source of runners to the UK strawberry industry during the time, and considering the quantity of plants being grown in the UK each year, which in 2009 amounted to around 75 million plants

(Anonymous, 2009b), the majority of which are imported from abroad (Table 4-1), the figure of 56 cases of undetected infested imports, might be considered as conservative. This however does not exclude the possibility of many more undetected imports of infected plants that the PHSI were not informed about. In fact, through this study, it has been seen that, even though the records indicate that a total of 89 farms throughout the UK had been infested during 1982 to 2007, 90% of the growers interviewed in Kent in a study on the sector in 2009 declared that they had encountered the disease on their land during their lifetime (Section 4.4.1.2). This implies that the disease might have been more widespread than records declare. In addition to this, two of the three years with the highest recorded incidences of strawberry black spot coincided with an intensification of farm inspections, and these were confirmed only after laboratory analysis, implying that the disease was more widespread than was thought but was not recognised because of the lack of visible signs through most of the year.

The case of the introduction and spread of *C. acutatum* in the UK is an example of the difficulty in halting the entry of quarantine organisms, especially if they are not easily detected by visual means. Not only was the UK phytosanitary system unable to stop the spread of the disease, but so was the wider EU phytosanitary system, whereby just 16 years after the pathogen was first listed as a quarantine pest (Anonymous, 1992), it had to be declassified because it had by then spread throughout the European Union (Anonymous, 2008). Although this is not the only case of a pathogen slipping through the phytosanitary system, there are cases where the system was efficient enough in stopping the establishment of a quarantine pest even after entry, such as the case for *Xanthomonas fragariae* in the UK. The pathogen had entered the UK in May 2004 on plants from the Netherlands, which were then sold to four different farms (Matthews-Berry and Reed, 2009). Following notification to the relevant authorities by one of the growers involved, an investigation was carried out and the growers were given the option to destroy the plants or long-term containment; i.e. the plants would be kept for fruit production and measures taken to curtail the spread of the disease. The second option was chosen by the growers and, following the implementation of the PHSI and the Plant Health Service recommendations, by 2009 the disease was deemed to have been successfully eradicated (Matthews-Berry and Reed).

Success and failure of a Phytosanitary system does not always depend on detecting the pathogen at the border. The EPPO Phytosanitary procedures for strawberry plants accept an infection rate of up to 1% with a confidence level of at least 99% (OEPP/EPPO, 2008b). Some even suggest that a successful quarantine system could be measured by the number of interceptions and the action taken to eradicate pest outbreaks (Mumford, 2002). This would make the UK strawberry black spot episode a relative success, since not only was the disease intercepted at the BIPs in 57 different instances, but action and recommendations were taken every time the relevant authorities were informed of an outbreak. The reasons why eventually the systems in place did not succeed in eradicating the disease are thought to be twofold.

Firstly, although recommendations were made by the Plant Health Service in the 1980s and 1990s every time an outbreak was detected, very little follow up was made to determine whether the recommendations for grubbing and destruction of the infested plant material had been taken up by the growers. Secondly, and more importantly, unlike the case with *Xanthomonas fragariae*, the sheer volume of diseased plants that were being imported into the UK made it very difficult for the relevant authorities to stop the disease effectively at the BIPs. This was even more so, when the vast majority of infected plants were coming from other EU countries, which after 1992 were accompanied by a plant passport. Thus whilst the plant passporting system is meant to put the burden of responsibility on the plant nurseries selling the plants, to ensure that the plants are free of pathogens, many have raised doubts on its efficacy in preventing the movement of disease between EU member states (Brasier, 2008, Jones and Baker, 2007). In fact, as long as diseased plants continue to be sold at nurseries, the effectiveness of the phytosanitary system is hindered or limited in its capacity to halt the introduction and spread of alien pathogens throughout Europe.

In recent years, *C. acutatum* has been declassified as a quarantine organism by the EU. Records of incidences in the UK have also been at an all time low and the UK strawberry sector does not consider the disease to be a problem anymore (Section 4.4.1.2). The increasing use of protection through multispan tunnels has almost eradicated the disease since its main means of dispersal through rain splash has been eliminated, now that around 80% of the strawberry crop area is under cover (section 2.3.3.2). Nevertheless, lessons learnt from the entry and spread of this disease in the

UK, and the weaknesses that enabled it, could help the strawberry industry to safeguard themselves from future alien disease epidemics. Through greater control from the industry itself, and an improvement in plant health at source nurseries, intra-European movement of plants could pose a much smaller risk to the phytosanitary controls at national borders.

3.4. SYNTHESIS

The objectives outlined in the introduction to this chapter, together with the use of long-term disease datasets, have led to a better understanding of the impact of plant disease on the British strawberry sector. Plant disease has been shown to be a force for change in the industry that has led to the development of disease resistant varieties, use of plant protection products and use of protected cultivation to minimise the impact of disease. These practices have led to increased yields, larger farms and a specialisation of the sector (Section 2.3.3). Concurrently, we have seen the susceptibility of the UK strawberry sector to alien diseases, and what the sector can do to protect itself from future entries of non-native plant pathogens.

This chapter has also shown that disease can influence the sector differently depending on where production is taking place, suggesting that it could act as a force in geographic selection of the sector. Thus whilst in the 1920s strawberries were grown throughout the UK, production is nowadays focussed in a number of counties where the sector has become specialised and farms are relatively larger. This movement however, was not necessarily caused by disease pressure, since some of the counties which have experienced an increase in farm size such as Kent, actually have obtained some of the highest incidences of disease, particularly for *P. fragariae* and *V. dahliae*. In fact, this study suggests that Kent might not be the ideal location to focus an industry in terms of these two diseases. So why has this shift in strawberry cultivation occurred? Are British growers growing strawberries in the wrong place? How important is plant disease for UK strawberry growers? And do growers struggle to deal with plant disease, or is it just one, or the least of a number of problems they deal with nowadays?

Whilst this study is innovative in using existing long-term datasets to assess the influence of plant disease in shaping the UK strawberry sector over a long-term time period, it manages to raise as many questions as answers. In order to answer some of these, one must first understand the processes of change taking place at the farm level. Data from the farms themselves are needed to illustrate the decision making processes of growers and the role of plant disease in these. This would lead to a better understanding of the impact of plant disease on the strawberry sector and how susceptible the industry actually is to disease.

In the next chapter, data from growers are collected through a social science study in order to assess the importance of plant disease in the UK strawberry sector and its role as a driving force for change today, and possibly in the future with climatic change.

Chapter 4 Shape and structure of the UK strawberry industry

4.1. INTRODUCTION

In order to understand the processes affecting change in a particular sector in agriculture, one has to first understand the conditions that initiated change. A good start would be to study its recent past, to see how these conditions came about, and understand the reasons that linked the various processes together.

4.1.1 Aim and structure of this chapter

In this chapter, a social science study of the British strawberry sector is undertaken to build up on the data obtained in the previous two chapters. The aim of this social science study is to reach an understanding of how the strawberry sector is set up and what the driving forces are behind change in the sector. Some of the answers raised in the previous chapters on the impact of plant disease will be assessed. Other factors affecting the sector will also be assessed, and the role of plant disease in light of these other forces will be studied. All of this will contribute towards a better understanding of the vulnerability and resilience of the strawberry sector to plant disease. The outcome of this would then contribute to a better understanding of how susceptible the strawberry sector is to the potential impacts of climate change on plant disease that will be discussed in the later chapters.

Due to the amount of data generated through this social science study, the results and discussion in this chapter will be subdivided into three broad themes as follows:

1. Structure and shape of the strawberry sector
2. Plant disease and its influence on the strawberry sector
3. Challenges facing the UK strawberry sector (includes labour issues and regional challenges)

Whilst the results and discussion are subdivided, there will only be one introduction and methodology for the chapter, as the same methodology is used for all three themes.

4.1.2 Productivist vs post-productivist agriculture

In a study of specialist food businesses in the Scottish-English borders, Ilbery and Maye (2005) suggested that one of the key reasons why some farmers switched from being productivist to more post-productivist is to better control their supply chain and to retain more of the ‘added value’. This does not come as a surprise when one considers, as suggested by Pretty (2001) in (Ilbery *et al.*, 2005), that only an estimated 7.5% of the final retail price of food in the UK returns to farmers, compared to a figure of 50% over 60 years ago. By 2006, over 70% of the UK grocery market was controlled by the largest four supermarket chains (Dibb *et al.*, 2008). This gives extraordinary power to the large multiples to influence anything from product type, source and especially price. According to a review on the government’s role in supporting sustainable supermarket food by the Sustainable Development Commission, stakeholder consultations suggested that suppliers were being ‘squeezed’ by supermarkets to such an extent that they were being put out of business (Dibb *et al.*, 2008). The report goes on to say that supermarkets have a very poor record when it comes to the treatment of their suppliers. A case in point is the British mushroom industry. Retail prices of mushrooms have stagnated since the mid-1990s, mainly following a move by ASDA in 1996 to fix prices at £2.40/kg. Retail price stagnation has meant that the British mushroom sector has been deprived of the necessary resources to enable them to restructure themselves and compete with foreign imports (Ilbery and Maye, 2008).

It is for this reason that the market for ‘alternative’ food is often growing out of the need of many consumers to avoid buying food specifically from supermarket chains. For some consumers, farm shops and other alternative food networks often provide them with the opportunity to avoid the supermarket mode of retailing food, specifically because of their dislike of the multiples. These consumers may prefer, given the opportunity, to buy local, quality food through shorter supply chains (Holloway *et al.,* 2007). In this case, vicinity to the market is often an important issue and farms in the urban fringe often do well because of this, receiving a high footfall of customers (Blair, 1980, Ilbery and Maye, 2010). Notwithstanding the opportunities in urban areas, farms adopting alternative food networks are often concentrated in more marginal farming areas that tend to be unprofitable for intensive farming. In fact, high input-high output farming tends to be spatially differentiated, with the core farming areas remaining essentially productivist and the more marginal areas often embarking on diversification schemes and focusing on the production of specialist foods for niche markets (Ilbery and Maye, 2010).

Notwithstanding this spatial differentiation, these two phases of agricultural change – productivist and post-productivist - often co-exist in what is frequently described as a multifunctional agricultural system (Potter and Burney, 2002). This co-existence is often mirrored in the way the two types of farming make use of the same input suppliers within their supply chain (Ilbery and Maye, 2005). They may also co-exist in the same region and occasionally on the same farm; the reasons why farmers tend to embrace one instead of the other could be anything from the availability of capital assets, ownership of the farm, vicinity to the market, inheritance of the farm, reluctance of farmers to abide by supermarket standards, and a farmer's partiality to managing a big business.

4.1.3 Impact of supermarkets on UK agricultural restructuring

Supermarkets have been a major driving force behind agricultural change, particularly in the fresh produce industry (Carter *et al.,* 1993, Fearne and Hughes, 2000, Hingley, 2005). This has been driven by the popularity of fresh produce in the supermarket chains. In fact, fresh produce has become a 'destination category' as retailers call it and shoppers often switch stores based on whom they wish to purchase their fruit and vegetables (Fearne and Hughes, 2000). Since the late 1980s, the fresh produce department within supermarkets has moved to the front of the store and has doubled its shelf area. ASDA alone has benefited from a 50 per cent increase in fresh produce sales just by relocating their fresh produce from the back to the front of the supermarket (Fearne and Hughes, 2000). Footfall and overall store sales are a major reason for this shift in importance given to fresh produce by supermarkets, and this is often augmented by numerous promotions on fresh fruit and vegetables to attract customers to their stores (Taylor and Fearne, 2009). Many retailers argue that promotions are necessary to their business, at least to beat off their competition and attract customers.

These promotions and increasing market share of domestically produced fresh fruit and vegetables have had a major impact further down the supply chain. Whilst consumers have a greater choice of top quality produce all year round, suppliers are continuously squeezed to provide greater volumes at lower prices. The success enjoyed by the retailers has not translated into an equivalent success for the suppliers, particularly since there is intense pressure on the margins enjoyed by the latter (Fearne and Hughes, 2000). Martin (2005)(pg 559) suggests that "power is notably imbalanced in fresh food relationships, in favour of retailer buying organisations." The threat of punitive action is often used by retailers over those suppliers who do not conform to their wishes (Fearne and Hughes, 2000, Hingley, 2005, Rogaly, 2008).

Apart from the price, retailers also affect the quality, shape, type and timing of when fruit should be on the market. The retailers' need for greater consistency in the quality of fresh produce led to their search for greater control of the market through their own quality standards, distribution networks and, indirectly, through partnerships with co-operatives or individual growers. This led to them dealing with fewer, larger, technically efficient and innovative suppliers (Fearne and Hughes, 2000). This constriction of their supply base, in conjunction with tougher standards, has put many producers out of business, particularly the smaller ones that go into increasing debt and lack the resources to expand (Ilbery and Maye, 2008, Rogaly, 2008). This has also been the case for pick-your-own farms (Carter *et al.*, 1993). The only survival strategy for some farmers has been to intensify production and gradually supply greater volumes, and become involved in the packing of their own products, and sometimes also imports (Fearne and Hughes, 2000, Rogaly, 2008). Having their own packhouse often gave growers added leverage, since packhouse owners could often reject produce on 'quality' grounds, when there was a surplus of fruit (Rogaly, 2008). Notwithstanding the power imbalance and the risks involved for suppliers, it does not mean that the latter do not want to enter into commercial relationships with the large multiples, since they remain by far the most consistent market outlet for their produce (Hingley, 2005).

These relationships sometimes develop into collaboration in the food chain between supermarkets and growers or grower bodies, since the former can gain from the assistance of specialist knowledge from the latter in forecasting sales (Fearne *et al.*, 2006). The need for such collaboration arose from cases involving the mishandling of promotions in supermarkets that led to great losses and wastage due to the miss-reading of consumer preferences (Fearne *et al.*, 2006). Variability in consumer demand is common in supermarket chains and is often product specific. This could be influenced by seasonal consumption patterns or short-term fluctuations such as weather related influences (Taylor and Fearne, 2009). One such example of collaboration occurred in 2003 between Sainsbury and KG Growers (marketing body for soft fruit). Following an unprecedented wastage of strawberries after a particularly cool Wimbledon in 2002, Sainsbury's agreed to have a representative of the supply chain as an implant working with them from within. Her mandate was that of "*assisting the accurate forecasting of department 882 (soft fruit) to maximise sales and reduce waste across the Sainsbury's estate*" (Fearne *et al.*, 2006)(pg 4). Through the implant, they estimated that every 1 per cent of forecast inaccuracy was 'costing growers dearly in lost sales and avoidable waste'. This example of collaboration was a success. Following changes in Sainsbury's systems, strawberry sales alone reached record levels of over £3 million per week.

Collaborative planning and forecasting have nowadays become common between retailers and manufacturers of branded/packaged groceries. This benefits suppliers who seek to capture the cost benefits of such collaborative activity, but also retailers in minimising loss and maximising profits by eliminating promotions when they are not needed (Fearne *et al.*, 2006).

4.1.4 Change in the strawberry industry

The £3 million per week sales mentioned in Fearne *et al.* (2006) was not always the case for the strawberry sector. According to Hughes (1996), whilst household consumption of fresh fruit experienced very modest growth, from 28kg to 33kg per capita, the market position of strawberries deteriorated between 1969 and 1995 by around 14.5% per year. The same author also suggested that until the mid-1990s supermarkets had shown significant growth in strawberry sales. Thus it is likely that the decline came at the cost of traditional greengrocers, farm shops and “pick-your-own” outlets.

According to Carter *et al.* (1993), up until 1991-1992 open ground cultivation accounted for 89 per cent of the land area used for strawberries. The remaining 11 per cent used some type of protected cropping technique, mostly inexpensive, low technology aids such as film covers. However, these were rarely used to extend the season. Until then, only 1% of the land was used to extend the season, through glasshouses or walk-in polytunnels.

With regards to sales at that same time, only 30 per cent of fresh strawberries were being sold via supermarkets, with the remainder going to wholesale markets or farm gate sales, local retailers and local caterers (Carter *et al.*, 1993). For most of the growers, strawberry production was still a relatively minor aspect of their total farm output and used only as a source of supplementary income. This was particularly so for the open ground growers. For those using protected systems, their main markets were supermarkets. Although being a minority, these growers represented a large percentage of the total main season supplies to the retail sector. As a result, they often had the capital to invest in large-scale and intensive systems necessary for extended season cropping.

4.2. RESEARCH DESIGN

In social science research, there are different ways in which the relationship between the researcher and the researched is expressed. Cloke *et al.*, (2004) describe four different relationships that can be built between the researcher and researched when the former is collecting data in human geography:

1. *Robotic relationship*: Where the researcher uses other people's surveys (e.g. agricultural census data, records). Data are effectively pre-constructed and there is no direct interaction between the researcher and the researched.
2. *Remote relationship*: The researcher frames the questions, but there is a lack of face-to-face contact (e.g. postal questionnaires). Such remoteness screens out subjectivity, but responses depend on how well the question is worded and interpreted.
3. *Interactive relationship*: The researcher begins with a set of questions, but the data are co-constructed as the researcher and the researched work through the discussion (e.g. semi-structured face-to-face interviews). Original questions may be diverted or even become redundant. Interaction will differ according to the power relations involved.
4. *Involved relationship*: The researcher is further immersed in the social situation of conversation (e.g. reflective interviews, discussion groups). Here the notion of getting 'true' answers is replaced by the potential for dialogue.

Up until this chapter, most of the data obtained about the sector were of the Robotic Relationship type, as it was not obtained from the sector directly by the author, but through other sources, such as government statistical records and reports of disease outbreaks on farms held in MAFF archives. This made any control on the type of data obtained quite limited, since often one had to make do with the available data and the researcher could not re-investigate certain issues that needed further elaboration.

Moreover, the nature of the objectives of the research necessitated the collection of data through methods that had not previously been used within the sector. Thus, following the use of secondary data to build an image of the sector in the previous chapters, it was decided to use social science research methods to build data on two main themes:

1. Firstly (this chapter), to investigate how the sector is currently structured and obtain information on the different production systems used on farms; how the farm operates; what the most common diseases are and how the farmers deal with them; and the dynamics that simultaneously affect all of these things and effect change within the sector.
2. Secondly (discussed later on in Chapter 6.2), to examine how climate change may affect the sector. Are growers at risk from climate change and how can they adapt to the threats or opportunities brought about by climate change? How will the dynamic forces affecting the sector today interact with or counteract the threats or opportunities brought about by climate change?

This necessitated the collection of primary data on the strawberry sector and a dialogue with key decision makers in order to understand the main mechanisms creating change. This was achieved in two ways. The first was by building a "remote relationship" through a postal questionnaire survey of strawberry growers. This would help provide a clearer idea of how the sector works.

The next phase of data collection was to build an "interactive relationship" with the sector by focusing on a particular case study that would involve the whole strawberry supply chain. Given the scope of the study, it was decided to focus the case study on two regions within the UK. Studying two different regions would permit a good comparison of geographical differences and help understand how existing realities in different regions affect the sector in different ways.

Data for the case studies were collected through semi-structured interviews with key targeted players in the strawberry industry. From this point onwards, the term industry is used to refer to the whole supply chain, not just the strawberry growers themselves. Thus other supply chain actors such as suppliers and retailers were included in the case study research. Although not involved directly in growing strawberries, these 'actors' have an influence on any processes affecting change in the sector. Moreover, any impacts on the strawberry sector could potentially have an impact further up or down the supply chain, which would also be the case with climate change.

The postal questionnaire and semi-structured interviews were used to collect data for both this chapter and for chapter 6 (section 6.1.4) which examines the impacts of climate change on the strawberry sector. Whilst the climate change data are analysed and discussed separately to simplify its interpretation, the methodology used is the same for both of these chapters and is described in the following sections.

4.2.1 First phase: Postal questionnaire

Building an effective questionnaire is a very demanding task (Sarantakos, 1994), requiring not only the construction of a set of questions that achieves its purpose in extracting the kind of information that the researcher requires, but also in making it attractive enough for the respondent to want to participate. This is even more challenging when using a postal questionnaire which, as Flowerdew and Martin (2005) suggest, has a lower response rate than other methods of data collection such as interviews or telephone surveys. Nevertheless, it does have a number of advantages over interviews in being cheaper to carry out, the ability to target a larger audience and responses that are less prone to interviewer biases. In the latter case, the respondent can feel free to reply as they wish without being worried about facing the person asking the question.

To be successful, however, a questionnaire needs to have a number of characteristics:

- It should have a flow that follows a sequence, starting with general questions that lead to more specific, difficult or controversial topics later on.
- The questions should be simple and easy to understand, not to put off respondents from replying.
- It should avoid unnecessary jargon, which could be misinterpreted by the respondent.
- Questions should be clear and not lead the respondent towards a response bias.
- It should not be too long and take too much time to complete, otherwise respondents will be discouraged from completing it.
- It should avoid repeated questions that in some way or another ask the same thing.
- It should be tried and tested (piloted) on a small sample of the population to test the validity of the questions.

Thus building a questionnaire can often take longer to prepare than it does to analyse its responses, since many drafts might need to be prepared until a final version is ready to be sent out to the target audience.

The type of questions used in a survey can also have a significant effect on the analysis and type of results obtained, in particular whether the outcome is qualitative or quantitative. Questionnaires with a strong focus on close ended questions would generate mainly quantitative data, whereas open ended questions lead to the construction of qualitative data which are often more difficult to analyse or quantify. For instance, the following question is composed of two parts.

Do you think climate change will have any impact on your business?

Yes ☐ *No* ☐

Why?

The first part is quantifiable, leading to a result which can be converted into a fixed percentage. The second part of the question is open-ended and sheds light on issues that otherwise would not emerge if the question was limited to specific choices; it could lead to many different types of response, ranging from negatives (affecting them negatively), positives (bringing them advantages), and to denial (they don't believe in climate change). This also gives flexibility to the questionnaire by not omitting the possibility of obtaining responses which the researcher did not think of. It can also provide the researcher with the opportunity to discover trends or processes that were not known previously. Thus, depending on the kind of data that the researcher is seeking, one can change the ratio of open/close ended questions in order to obtain more qualitative or quantitative data.

For this study and at this stage of the social science research, it was necessary to generate some general information on the sector, including statistics on the farm business, production methods used, plant diseases and their management, and growers' opinions on climate change. Thus a large proportion of close ended questions was used in order to obtain sufficient quantitative data that would provide a strong foundation for explaining trends at later stages. On the other hand, about a quarter of the questions were open ended; these were included to help understand the dynamics of the sector. They were also fundamental in building ideas for the questions that would be used in the interviews in the next phase of the social science study.

4.2.1.1. Building the questionnaire

The questionnaire consisted of 42 questions and was divided into seven sections, as follows:

Section A: General Information

Section B: Production methods

Section C: Threats and opportunities to the strawberry sector

Section D: Strawberry diseases

Section E: Your future in Strawberry production

Section F: Your general farm business

Section G: Sales and marketing

The sections were determined according to the information that needed to be collected at this stage. However, the sequence of the different sections and their titles changed throughout the process of drafting the questionnaire.

4.2.1.1.1. Section A: General information

This section obtained the grower's contact details and address. Its main purpose was to provide names of some growers that could be contacted for interviews in the eventuality that they were located within the chosen regions of the case study. The postcode was also requested so that they could be mapped using ArcInfo at a later stage.

4.2.1.1.2. Section B: Production methods

The aim of this section was to obtain information that would update some general statistics on strawberry farms, such as production methods used, cultivars used and where they were obtained, and cropping time. This, together with the previous section, was placed at the beginning of the survey since they were considered not to be controversial. This would allow the respondent to 'warm up' to the questionnaire in preparation for the next section.

4.2.1.1.3. Section C: Threats and opportunities to the strawberry sector

This was considered to be one of the most important sections. It would be used to generate ideas and themes that could be further probed in the interviews in the next stage. It started by asking growers about the current threats and opportunities that they face as strawberry producers. This was then followed by a number of questions about climate change, including whether they thought that climate change would affect their business. The climate change questions were purposely placed after the current threats and opportunities questions so that the climate change theme would not influence the growers' response to what they see as a threat. The aim was to see how many respondents were already thinking about climate change as a threat or opportunity. Moreover, the respondent was given the opportunity to skip the questions about climate change if they did not believe that their business would be affected by it in the future. This would allow the climate change sceptics amongst the respondents to go straight to the other sections, thus avoiding some respondents from getting unnecessarily "irritated" by responding to questions they might think are irrelevant.

4.2.1.1.4. Section D: Strawberry diseases

The aim of this section was to obtain information that would link with and add information to an earlier chapter about plant disease. Perceived to be a non-controversial section, it was placed straight after the climate change section to engage the respondent once more into simple questions before moving on to more confidential questions at a later stage. The only confidential question in this section was put at the end, and asked the grower for the cost of pesticides spent in a growing season. This would be useful later on to extrapolate overall costs met by a farm.

4.2.1.1.5. Sections E and F: Present and future general farm business

These two sections were also considered as non-controversial, and were used to obtain further information from the growers about their perceptions of future trends of growth or decline in the sector

4.2.1.1.6. Section G: Sales and marketing

This final section was placed where it was because it requested confidential information. The questions used here would help build information on farm costs and current, future and past marketing practices. Information obtained here would also help feed into the interviewing phase to see how these factors influence restructuring on strawberry farms.

4.2.1.2. Types of questions used

A mixture of questions types (Sarantakos, 1994) were used, ranging from:

- Simple questions where the respondent had to tick a box or fill in numbers or percentages
- Scales of increasing strength
- Constant sum scales
- Ranking scales
- Open-ended questions
- Attitude batteries (scale from 1 to 5)

These were used to provide the simplest and most effective way for the grower to respond to a particular question. The form of question used depended on the type of question and response being requested from the growers.

As explained earlier, various drafts of the questionnaire were prepared and improved, and a sample was also sent to the Technical Director of a large marketing body for his feedback. This enabled the completion of a final draft that was 'tested' on a small sample of 4 growers before minor corrections were made and a final draft was available for use amongst the sector.

4.2.1.3. Sampling the population

For the objective of this study, collection of data directly from growers was going to be challenging as there is no public access to a list of strawberry growers. Limited contact details were available on the web for small growers advertising themselves to enable direct sales. In addition, a few large farms had websites that were used to attract foreign labour as pickers during the summer. On the other hand, a list of soft fruit growers is held by the Horticultural Development Council (HDC), which includes soft fruit growers that have turnovers greater than £60,000 per annum. In the absence of a proper sampling frame, the HDC kindly agreed to send out a questionnaire to strawberry growers, reaching potentially 300 soft fruit growers, many of whom were growing strawberries.

The lack of an easily available list of growers with contact details, and the willingness of the HDC to send out a questionnaire on the project's behalf, were amongst the main reasons for opting to choose a postal questionnaire. Moreover, there was a need to target as wide a sample as possible of the strawberry sector. Strawberry growers are distributed throughout the country, so it would have been an expensive and time consuming process to visit many farms over such a wide distribution. A telephone survey would also have been unfeasible since the HDC could not give out telephone numbers. Thus a postal questionnaire was found to be the best option.

To encourage response rates, the HDC sent out the postal questionnaire accompanied by a covering letter written by the team at Warwick HRI, and a self-addressed and stamped envelope (SASE). The questionnaire was sent out at the beginning of April, 2009 and a month was allowed for responses to arrive before the HDC forwarded all completed responses to Warwick HRI.

In addition to the growers contacted via the HDC, more than 60 growers whose contact details were available on the web were invited to participate in the survey. Forty accepted and were sent a copy of the questionnaire, together with a covering letter and an SASE. Of these, 10 returned the completed questionnaire, bringing the total to 33 completed questionnaires and just over 10,000 tonnes of production.

To increase the numbers further, an agricultural advisor to the strawberry industry agreed to encourage growers to complete questionnaires during his routine advisory farm inspections. A further 5 questionnaires were added this way. Finally, direct contact was made with several of the largest growers, resulting in 3 more questionnaires being completed. This brought the total to 40 completed questionnaires and a tonnage of around 16,500 tonnes.

Three further questionnaires were completed during the interview phase of the project, bringing the total to 43 completed questionnaires and 17,000 tonnes. Whilst it is recognised that the sample may not be representative of the total population, it nevertheless is sufficient to provide much-need information and to begin to highlight some of the key concerns affecting growers that could be further pursued in the next stage of the research process.

4.2.1.4. Analysing the data

Quantitative data from the questionnaires were tabulated directly into an excel spreadsheet. The more qualitative data and responses to open-ended questions were coded and categorised, with a few themes emerging. These themes were then used to build up questions for an interview schedule that would be later used in the case study in the next phase of the research.

4.2.2 Case study: Interviews

The next phase was to further complement the postal questionnaire results and the data obtained from earlier phases of the study by investigating the process and drivers that bring about change in the sector through case study interviews in two selected regions. Interviews were seen as the best way of doing this, especially by targeting the whole supply chain, including growers, their suppliers and the retail sector. Interviews would enable the generation of data that would allow the researcher to explore deeper underlying issues and to interact with the interviewee by having a wide-ranging and in-depth discussion (Flowerdew and Martin, 2005).

4.2.2.1. Setting up the case study

Following the analysis of data obtained in earlier phases, it was decided that the case study should focus on two geographically separated regions. Following careful scrutiny of the data, it was decided that the two regions to be studied should be Kent and the East of Scotland. The following reasons were taken into consideration:

1. The first and most important is that, since the impact of climate change was the main theme of this study, the two regions should have very different climate change predictions. From the probabilistic projections of plant disease obtained in chapter 5 (section 5.4), it was evident that whilst Scotland and Northern England were predicted to have the greatest change in plant disease incidence, Kent would have only slight changes or even remain the same with respect to

disease incidence for the three diseases being studied. These would be used to elucidate responses from the growers on climate change impacts and adaptations.

2. The weather of the two regions is quite different with Scotland being much wetter and colder, whilst Kent is amongst the warmest and driest areas in Great Britain, thus affecting crop productivity and disease incidence differently in the two regions.
3. There were enough growers in both regions to enable sufficient participants to meet the target of 20 growers per region.
4. The Scottish strawberry sector had been a smaller player through most of the study period between 1920 and 1990 (see Figure 2-10), whereas the Kent based industry was considered to be one of the key players in the sector; some of the Marketing bodies were also based in Kent. Yields in Scotland were also found to be lower than on the average English farm. This gave rise to the possibility of comparing a highly developed sector in Kent with a less developed sector in Scotland.
5. The two regions are located at different distances from the main markets in Great Britain, opening up the possibility of different ways of marketing the crop and adapting to the different types of market available.

Unlike the postal questionnaire, the case study sample also included suppliers and retailers that feed into the sector in these two regions. These would be identified at a later stage through the growers' responses.

4.2.2.2. Setting up the interview schedule

For the purposes of this study, and considering the type of data sought, a semi-structured interview was deemed to be the best interviewing method to be used. This type of interview lies somewhere between a structured interview (in which respondents are asked fixed questions and kept within a strict interviewing schedule) and an unstructured interview (which has no strict procedures to follow, no order of questions and could allow the conversation to flow in any direction) (Sarantakos, 1994). The semi-structured interview used in this case had a number of fixed themes which emerged from the postal questionnaire and areas within the themes, where the discussion was allowed to flow quite freely.

Once the themes had been identified and the type of interview schedule chosen, a number of questions were used to discuss certain themes with the respondent.

A number of drafts were prepared until the final interview schedule was ready for use. Feedback from a mock interview with the editor of The Organic Way of Garden Organic was also taken into account. The schedule was divided into 4 sections as follows:

4.2.2.2.1. Section A: The Farm business

This section was further divided into three themes. The first covered a number of general questions regarding the ownership and size of the farm, and the relative age of the respondent. The remaining questions related to issues arising from labour, such as cost and supply.

The next theme covered *Farm business and drivers affecting the sector*. Within this, the respondent was asked about the production system, how they saw the future of the sector, and what they think are the most productive methods. They were also asked about the marketing methods used and their relationship with the supermarkets or market.

The third theme was titled *Strawberries in the area* and probed issues arising from the different geographies of the two regions, such as local threats and opportunities and why they chose that area to set up their business.

4.2.2.2.2. Section B: Strawberry diseases and disease management

This section was divided into three themes. The first was titled *Importance of plant disease* and asked questions about the most frequent diseases and how they detect and identify them.

The next theme was titled *Disease management* and explored ways growers deal with disease and methods they use.

The third theme was titled *What does the future hold in terms of disease management* and included how changes in the pesticides directive might impact growers' livelihoods, and the extent to which this may be a threat to the industry.

4.2.2.2.3. Section C: Climate change

In this section of the interview, the interviewees were first asked whether they thought climate change would affect them; they were then invited to discuss how their opinions might change when shown probabilistic projections of plant disease for their region, and then the whole of Great Britain.

Threats that emerged from the analysis of the postal questionnaire were discussed to determine impact and adaptation capacity. The issue of opportunities was then discussed with the interviewees.

4.2.2.2.4. Appendix: Impacts on inputs and outputs

Within this section, data that would help build supply chain diagrams were collected. Data collected here would also help build scenarios of where impacts will be most felt along the supply chain.

4.2.2.3. Choosing the participants

The interview sample population in each region was set at 20 growers, plus another 10-15 representatives of the supply/retail chain for the two regions together. This is deemed to be a large enough sample for qualitative research, where the main objective is not to be representative of a larger population but to provide detailed understanding of the main processes affecting structural change in the strawberry sector and growers' attitudes towards the potential impacts of climate change.

At this stage, the names and contact details of the latter group were not known. These would be obtained through the appendix section of the interview and by snowballing (asking the growers to recommend names of other growers and key supply chain actors that could be interested in participating in the interviews (Sarantakos, 1994)).

A list of growers in the two regions was based on two sources initially: a) growers that had responded to the questionnaire; and b) growers whose contact details were publicly available on the internet. At the beginning of the interview process, 10 growers in each region had accepted invitations to take part. The remainder would be collected through snowballing.

The interviews were carried out on the growers' property over a two week period in each region; in mid November 2009 in Scotland and early December 2009 in Kent.

The time of the year was specifically chosen to avoid periods when growers would be very busy.

The interviews were recorded using GarageBand® ’09 voice-recording software (by Apple), supplemented with notes taken during the interview. In total, 53 interviews were completed, 41 of which were growers (20 in Kent and 21 in Scotland), and 12 suppliers/retailers. This generated a large amount of vital qualitative data.

4.2.2.4. Transcribing and coding the interviews

Interviews were selectively transcribed into separate word documents. Transcriptions excluded some parts of the conversation that were considered to be beyond the scope or theme of the study. Information for Annex 1 of the Interview Schedule was summarised.

For the purpose of this study, every attempt was made to try and keep the analysis and interpretation of results as simple as possible, in order to obtain as clear and straightforward a coding practice as possible and without making it too complicated with the risk of falling into pitfalls of interpretation of some results.

Coding was done using software aids such as NVivo® 8 and Microsoft Office Excel® 2007. NVivo was first used to group the responses of all interviewees according to the question. The responses were then coded according to the response obtained, tabulated into an excel sheet that contained all the responses to the different questions, and divided by respondent and code type. Emerging categories from responses were filtered according to the category type and this resulted in a number of themes and interconnecting and independent issues. Quotes that highlighted certain issues were also collected for use later on in discussions[13]. For instance, one of the themes to emerge from this study was the impact of labour on the strawberry sector. Whilst being freestanding as a theme, it was influenced by other issues, such as regional differences in the industry, and also by plant disease. Categories such as the size of the farm and production methods used were also found to influence this theme.

[13] To keep the anonymity of respondents, their names were coded, and use of quotes was attributed to a particular respondent through their code. Codes give an indication of the location and the type of respondent as follows: K=Kent, S=Scotland, G=Grower, S=representative from supply chain, being either supplier or marketing body.

4.2.3 Data analysis

A number of statistical tools were used to analyse the data including:

- One and two-way, two-sample unpaired t-tests to assess whether the yield of two groups was significantly different,
- correlation analysis to test a linear correlation between two variables,
- ANOVAs, to test variables across more than two groups.

The statistical tests were done using GenStat® 12th edition. In various cases, the primary data were transformed into secondary data to obtain other variables that would give extra value to the analyses.

A number of graphical methods were used to display the results including tables, scatter plots, vertical bar charts, stacked bar charts, clustered column charts, pie charts and box plots. Locations of farms were also plotted using ESRI® ArcMap™ 9.2.

4.2.4 Outreach of the social science study

As a result of the postal questionnaire and case study interviews, 75 strawberry growers, with a combined output of around 32,000-33,000 tonnes, were represented. This equates to around one-third of the strawberry industry according to the 2008 DEFRA horticultural statistics (DEFRA, 2010). All surveyed strawberry farms were located between 0 and 150m above sea level.

The growers that responded to the questionnaire were distributed throughout Great Britain (Figure 4-1), with a heavy concentration in England and just one in Wales and seven in Scotland.

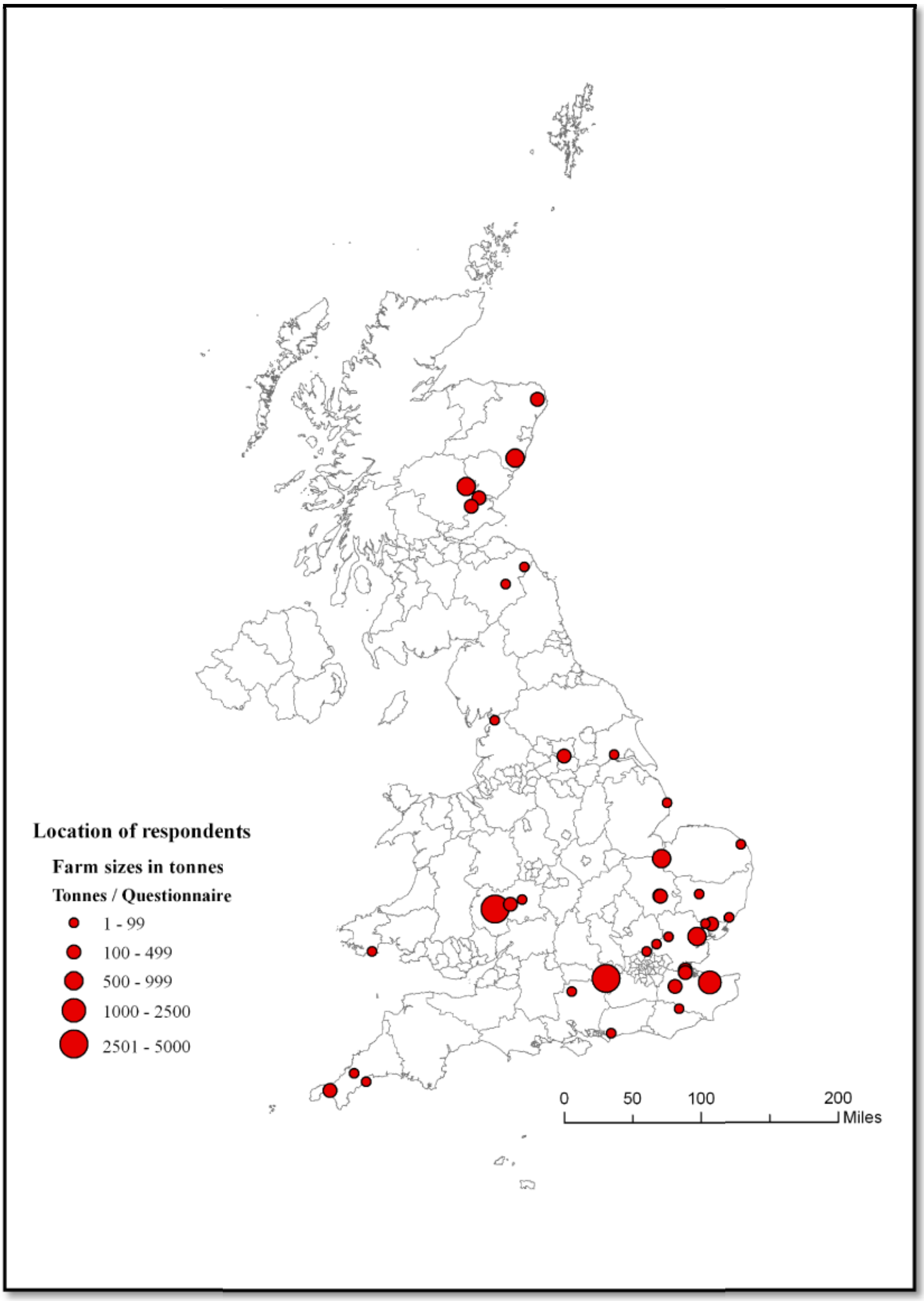


Figure 4-1 *Location of the* ***questionnaire*** *respondents and their relative farm size based on the latest production figures in tonnes*

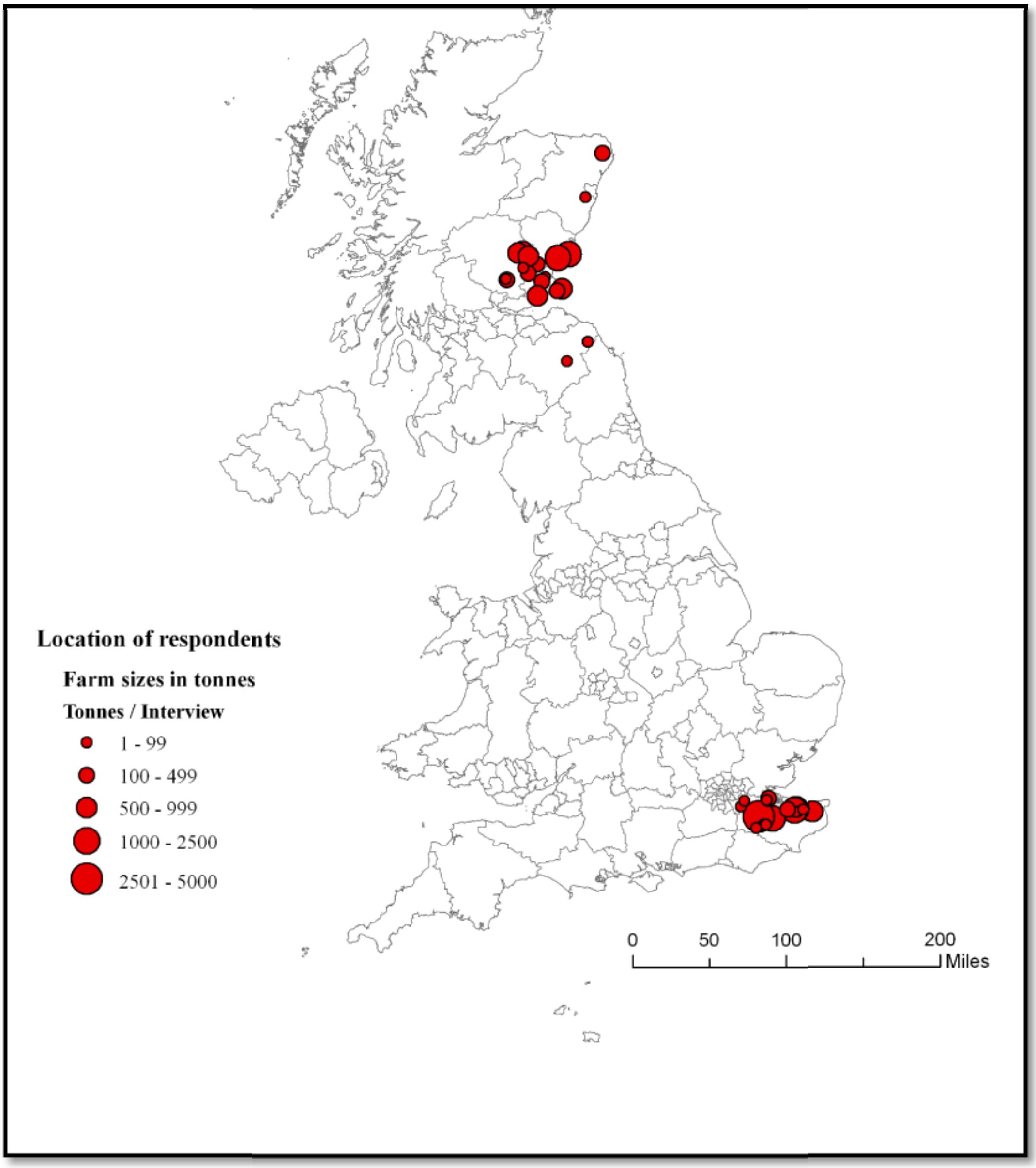


Figure 4-2 *Location of the* ***interview*** *respondents and their relative farm sizes based on the latest production figures in tonnes.*

41 growers were sampled during the case study interviews, with a combined output of 18,400 tonnes - 10,300 tonnes of which in Kent and 8,600 tonnes in Scotland. The Scottish study area was larger than Kent. The Scottish growers were distributed over approximately 3300 miles^2, with a majority located within the counties of Perthshire, Angus and Fife. The further one moved from this core area, the more difficult it became to find strawberry farms. In Kent, the study area was around 1100 miles^2 and all of the growers were located in the northern half of Kent, with two core areas forming around the Faversham/Canterbury area and around Maidstone.

4.3. STRUCTURE AND SHAPE OF THE STRAWBERRY SECTOR

For simplicity, this section is further subdivided into two. In the first part, the basic farm structure and the length of the growing season are analysed. The second part goes into further detail by analysing the business strategies of strawberry farms, and the structure and shape of the strawberry industry and how and why it has changed over the last few decades.

4.3.1 Results – Farm structure and length of growing season

In this section the farms are first divided into two categories that emerged during this study. The production methods used in both categories and their influence on the length of the growing season is then analysed. This is then followed by a discussion.

4.3.1.1. Farm structure

Two main types of strawberry farms were identified through the questionnaire survey and case study interviews, depending on the way in which they sold their crop. The first group generally sold most of their crop through farm shops or PYO, whereas the second group supplied almost their entire crop to supermarkets (Figure 4-10). Moreover, through the course of the research the farms within the first group used extensive production systems and rarely produced more than 60 tonnes of strawberries. On the other hand, the "supermarket-supplying" farms used intensive production systems and produced over 100 tonnes of strawberries.

According to Carter *et al.* (1993), this process of farm differentiation had already been occurring in the early 1990s. Thus in order to capture this restructuring of strawberry farms, the collected data were analysed according to the two main forms of marketing. Moreover, since the output of crop (tonnage) was seen to be consistently different for the two farm types, it was chosen as the indicator of choice. Subsequently, all grower responses, whether from the interviews or the postal questionnaires, were divided into two categories depending on the quantity of farm output, as follows:

- Small farm enterprises that produced up to 100 tonnes of strawberries.
- Large farms enterprises that produced over 100 tonnes.

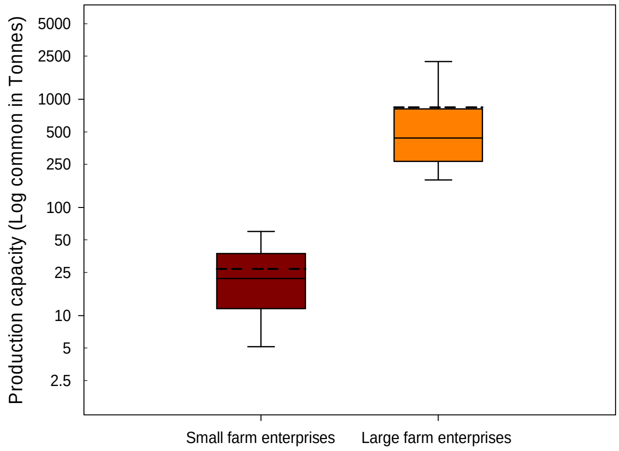


Figure 4-3 Box plot showing the output (in tonnes) of strawberries produced in the two different types of farms. The dashed line represents the mean while the whole lines are the median, upper and lower quartile, with the top and lower bar representing the 5th & 95th percentiles.

Although the 100 tonne threshold is an arbitrary figure, by dividing the farms into these two categories and using box plots, a clear separation was obtained (Figure 4-3). Moreover, on separating the farms into the two chosen categories, an equal balance of small (37 growers) to large farms enterprises (38 growers) was obtained for this analysis.

4.3.1.2. Production methods, yield and general farm characteristics

A number of farm variables were found to be significantly different for small and large farm enterprises (Table 4-1). Farm sizes were significantly different, with small strawberry enterprises having a smaller overall area than large strawberry enterprises.

Table 4-1 ANOVAs carried out to test the significance in the difference in the means of various variables for small and large farm enterprises.

Farm variable	Mean: Small farm enterprise	Mean: Large farm enterprise	P value	Degrees of freedom
Overall farm size (Ha)	84.3	267.0	< 0.001	72
Area used for strawberries (Ha)	2.816	36.618	< 0.001	72

Farm variable	Mean: Small farm enterprise	Mean: Large farm enterprise	P value	Degrees of freedom
Proportion of land used for strawberries (%)	10.5	24.7	0.003	71
Yield (Tonnes Ha^{-1})	15.727	23.409	0.016	56
Proportion of land under polytunnels (%)[14]	42.92	76.68	0.012	31
Proportion of plants being UK propagated (%)	77.1	47.6	0.009	40
Proportion of plants being propagated abroad (%)	18.6	52.4	0.002	40

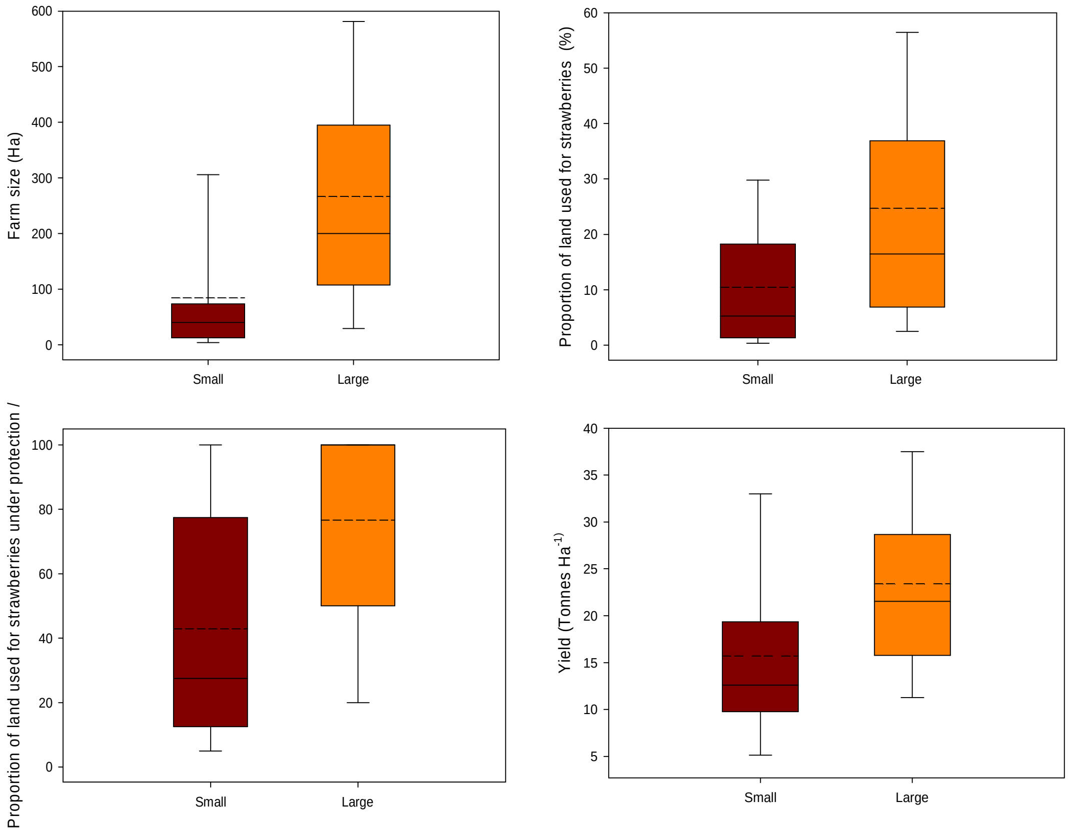


Figure 4-4 Box plots showing Farm size (top left) and proportion of land used for strawberries (top right) for the two categories. Also the proportion of land under polytunnels[15] *(bottom left) and the Yield (bottom right) for both categories. The dashed line represents the mean.*

[14] This value was calculated by taking the average of the proportions of land under polytunnels for each respondent.

Farms in the large enterprise category also used more of their land for strawberries, by almost 2½ times as much (Figure 4-4). In the 1970s and 1980s, this difference in proportion of land used for strawberries was not so apparent. Most of the growers involved in strawberry production used it as an extra crop to increase their income and secure labour for a few more weeks. As one of the grower pioneers in Kent explained during an interview:

"The soft fruit industry used to be a little bolt-on to the apple industry. When I first started growing strawberries it was six weeks. June to July and that's it. And it tended to be done by apple growers. What they were intending to do is to secure their labour for picking apples later on in the season. And it was a little cash crop. Sometimes it would never work you know, if you had a wet June the crop would be written off. So no one could actually become a big strawberry grower 'cos it was so weather dependent." KG1

The small farm enterprises encountered through this project are the remnants of that sector. On average, they use only around 10% of their land for strawberries (with median being even less, around 5%). Less of their income was dependent on strawberries, with around 22%, compared to around 65% for the large farm enterprises ($p = < 0.001$).

4.3.1.2.1. Use of protection

Polytunnels were used on a higher proportion of the land owned by large farm enterprises, with an average of 76.7% compared to less than 43% for small farm enterprises. When the actual area of the respondents' land was taken into consideration, the percentage of land under polytunnels for small enterprises was even lower, at around 25% (Figure 4-5). This led large farm enterprises to obtain higher yields, at around 23.4 Tonnes Ha^{-1} compared to 15.7 Tonnes Ha^{-1} in small enterprises (Table 4-1).

Since 1999, the area of land under protection has increased in both farm size categories, but especially for the large farm enterprises (Figure 4-5). This trend of increased protection started in the mid-1990s when an entrepreneur grower in Herefordshire introduced the use of Spanish polytunnels in the UK. At first, he imported them, but within two years he started manufacturing them himself. "*These*

[15] Calculated by considering the proportions of land under polytunnels for each respondent.

more extensive multi-bay tunnels ... were very thin steel, but gave a nice atmosphere for growing strawberries, and you could cover a very large area." KS1.

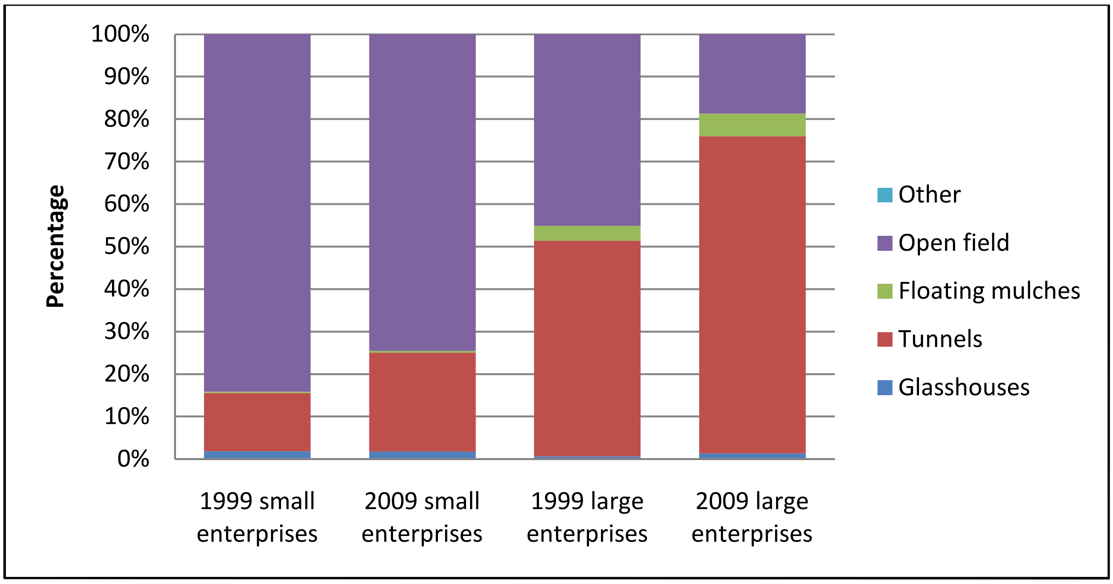


Figure 4-5 Change in the type of cultivation practices used between small and large farm enterprises (questionnaire data used). The figures used for this graph were calculated by taking the average of the actual area under protection for each respondent.

One of the factors influencing small farm enterprises to use less protection was consumer preference. As explained by a small farm enterprise in Scotland:

"Our customers just come for the fruit, because there's not many farms that grow outside anymore. And the customers tell us that they come because we grow them in an old fashioned way, outside. And we have people who phone up and ask if they are grown outside. We get emails as well asking us if we grow them outside." SG3

4.3.1.2.2. Varietal use

On comparing the types of plants used in the two farm enterprises, small farm enterprises sourced 81% of their varieties or plants from UK based nurseries compared to just 48% for large farm enterprises (t-value = 3.28; p = 0.002). As one prominent grower said:

"They weren't producing the right quality of plants. In part it was disease. I think what did for them at the end is that the sterling was very strong against the euro. So they got their plants cheaper from the EU. Now of course it's the other way. But to be honest they just weren't producing the right quality of plants, particularly on the 60 days plants." KG1

The most popular variety in both types of farm was Elsanta, which was also the most popular variety in the market. The ranking of the remaining varieties used by the different farm types was different, although the actual proportion was not found to be statistically significant except in two cases (Table 4-2). Symphony and Florence are late season varieties. Sonata is a June bearer that is often used as an early crop, and has the ability to produce a large proportion of first class crop. Evie is an everbearer resistant to high summer temperatures.

Table 4-2 Main varieties used in the two farm categories with the relative proportions in percentage, and the P value obtained with a one-way t-test

Variety	Small farm enterprises	Large farm enterprises	Probability (one way T-test)
Elsanta	34%	45%	0.128
Symphony	15%	1%	0.013
Florence	12%	3%	0.029
Sonata	4%	14%	0.053
Evie	3%	10%	0.067

The proportion of June bearers to everbearers was statistically different for the two farm categories (p = < 0.001) with small farm enterprises using more June bearers, whilst large enterprises used an equal proportion of June to everbearers (Figure 4-6).

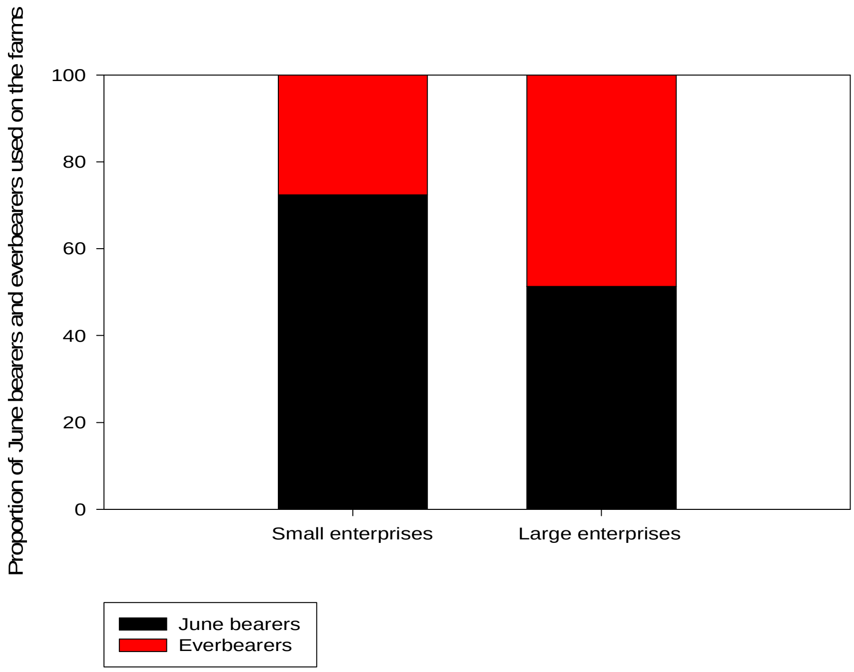


Figure 4-6 Stacked bar chart showing the proportion of June to everbearers used in the different farm categories

The difference in proportion of June and everbearers also affects the fruiting time in the two different farm categories, with small enterprises having a peaked season of around two months in June and July compared to a six months season (May to October) for large farm enterprises (Figure 4-7). This, in combination with increased use of protection, has brought about a lengthening of the season for the large farm enterprises. One of the grower pioneers in Kent described the impact of these new varieties on the development of the sector:

"Ostara was the first. And then Rapella was the mainstay for a long time. And then suddenly the strawberry producer could produce strawberries for a long time. And in the late eighties we were using French tunnels to bring the season forward, and that gave us quite a reasonable window. And it allowed our business to become a specialist soft-fruit business because they had a long cropping period and it had some sort of certainty." KG1

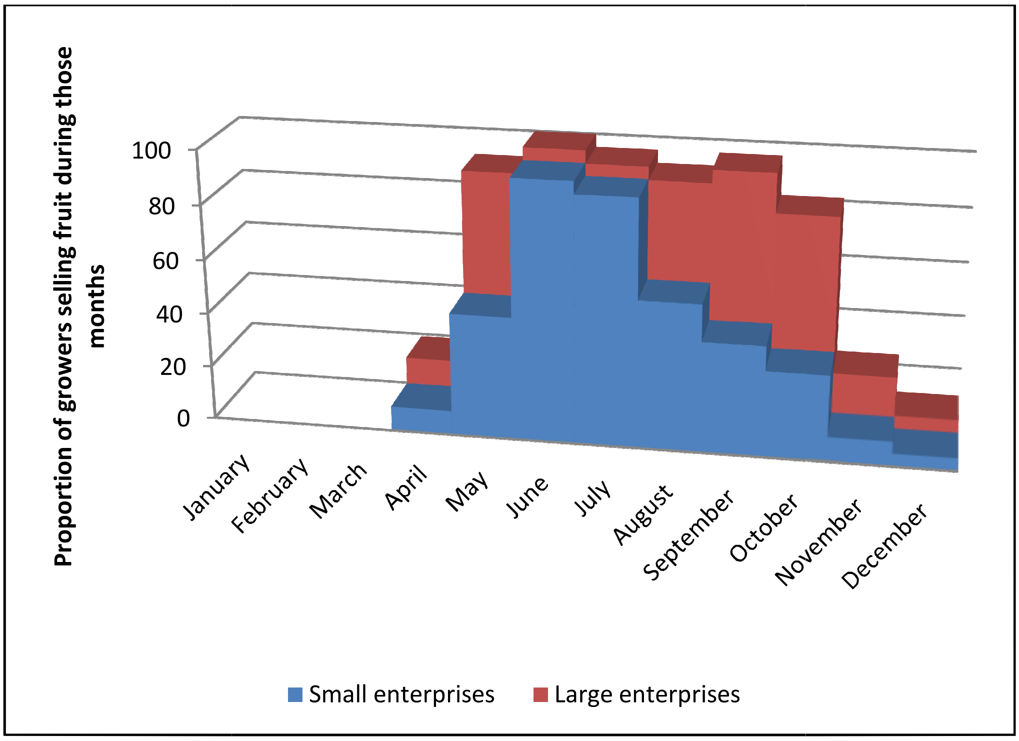


Figure 4-7 Distribution of fruiting season, indicating when strawberries are taken to the market

Small farm enterprises also keep their plants for a longer time period, for 2 to 3 years, whereas larger enterprises keep their plants mostly for 1-2 years (Figure 4-8).

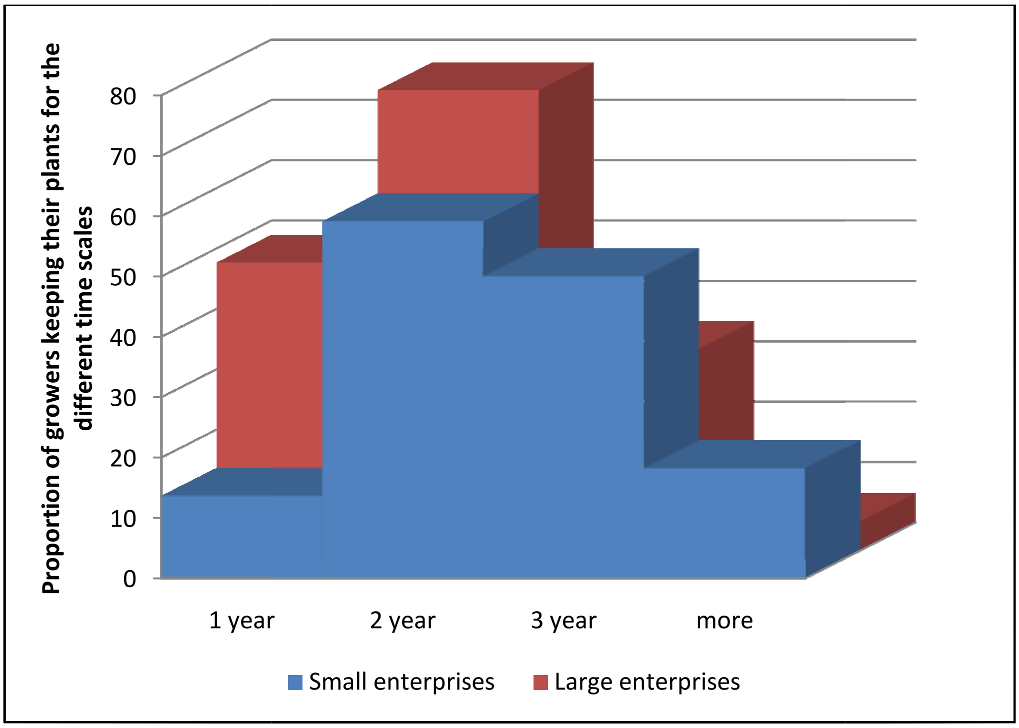


Figure 4-8 Duration that growers keep their plants

4.3.2 Discussion – Farm structure and length of growing season

The restructuring of the strawberry sector has followed a slightly different pattern to other major crops that restructured between the 1950s and the 1980s (Ilbery, 1988, Ilbery and Maye, 2008) (also section 2.4). Industrialisation has only occurred recently, with the development of large strawberry enterprises. Until the early 1990s, strawberry growers had a small proportion of their income coming from strawberries, and were involved in growing a number of other crops (Carter *et al.*, 1993). In fact, the small farm enterprises encountered through this project are the remnants of that sector. This meant that these newly emerging large farm enterprises had to pay greater attention to detail to the strawberry side of their business to maximize their gain. They introduced systems that would protect their crop from the rain, and nowadays over 80% of their land is under protection compared to just 25% in the small farm enterprises.

The emergence of the large farm enterprises is, through this study, thought to be responsible for the increase of the average size of the strawberry holding encountered in section 2.3.1.1. In fact, the increases have only been encountered in a number of counties, which coincide with those counties that host large farm enterprises. The existence of the large enterprises has also led to the increases in the mean national yield per hectare and in the total output of strawberries encountered in section 2.3.1.2. On average, one large farm enterprise contributes 31 times as many strawberries as a small farm enterprise, thus even though the overall number of holdings might have decreased, the growth of these farms was responsible for the increase in the national output of strawberries encountered since 1997.

One of the successes of these large farm enterprises was in spreading their crop over a longer season. This enabled them to avoid flooding the market over a short time period, and thus keep crop prices relatively stable at around £2000 per tonnes (Figure 2-14). This was achieved in two particular ways: the choice of varieties used and growing plants under protection. Whilst Polytunnels have brought the season forward into May by two to three weeks (Lieten, 2006), the use of everbearers has extended the season beyond the end of July to October. In combination, these methods have given growers the opportunity to lengthen the season from six weeks to six months. Nevertheless, the six week production period is still popular with small farm enterprises during June and July. In contrast, the six month extended season is almost exclusively used in the large farm enterprises.

One of the consequences of increasing production and productivity in large farm enterprises is that plants are increasingly being imported from abroad and kept for shorter periods. Moreover, since large farm enterprises deal with large volumes of plants, they often import them directly from abroad, either through a UK importer or else directly. A favourable exchange rate is one of the reasons for importation of plants, but foreign nurseries were seen by some in the industry to offer better quality plants. This nevertheless exposes the industry to the risk of importing alien diseases, as has happened with *Colletotrichum acutatum* in the 1980s and 1990s and *Xanthomonas fraariae* in 2004 (see section 3.3). This risk is exacerbated by the fact that plants are being cultivated for shorter periods (1-2 years), necessitating even more frequent imports. Small farm enterprises by comparison keep their plants for 2-3 years and buy most of them from local nurseries. This puts them at less risk of introducing alien pathogens. In light of this, large farm enterprises have a greater responsibility in limiting the entry of diseased plants into Great Britain through their acquisition of foreign sourced plants. Whilst control can in part help in reducing introductions, on its own it is not enough to eliminate them, as has happened with respect to *Colletotrichum acutatum* both in the UK (section 3.3.3.6) and in the rest of Europe (Anonymous, 2008). Buying plants responsibly on the other hand, is probably the best way of limiting introductions. Through the choice and actions of large farm enterprises, plant nurseries can be forced to prioritise plant health issues and take greater responsibility of their stock. In doing so, they will contribute towards reducing the risk of spreading diseased plant material through trade.

4.3.3 Results: Commerce and trade in the strawberry industry

In this second part, the business strategies of the different farm categories are first analysed. This is then followed by an analysis of the different production methods and geographic differences in the sector. And finally the structure of the supply chain is studied. This is followed by a discussion on the transformation and restructuring of the strawberry sector.

4.3.3.1. General farm business

Larger farm enterprises had a higher proportion (three times) of their business turnover coming from strawberries compared to small farm enterprises (Table 4-3). Large farms also spent more on pesticides in real terms, although the proportion of costs that went into buying pesticides was not found to be significantly different. Also, large farm enterprises spent a larger proportion of their turnover on labour, at about 44.6 % compared to 30.1% in smaller farm enterprises. The labour costs were also highly correlated with output in terms of tonnes of strawberries with a correlation coefficient (r) of 0.98 (Figure 4-9).

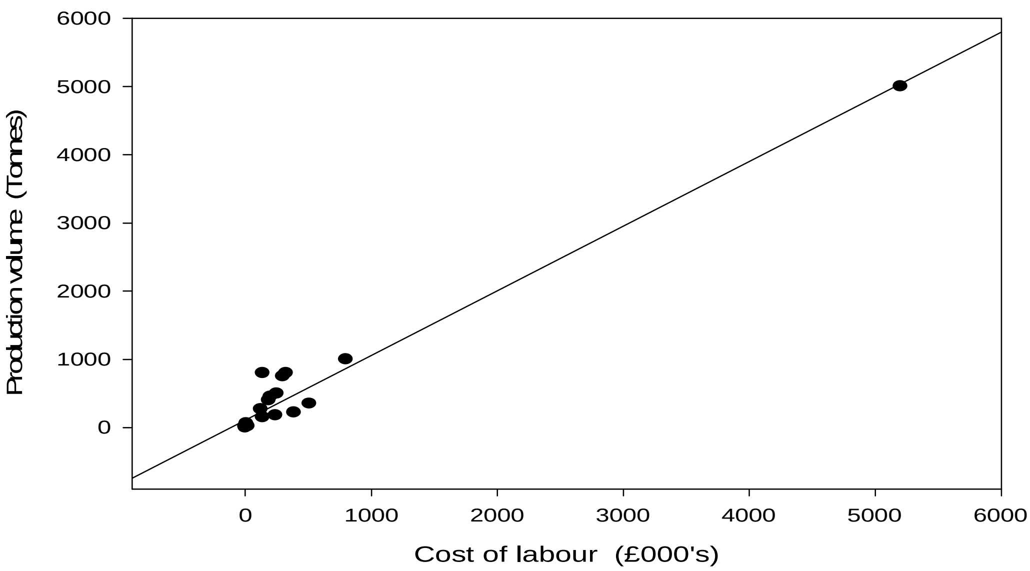


Figure 4-9 Labour costs related to output tonnage of strawberries.

Large farm enterprises were found to spend more in real terms towards the costs of their infrastructure; however, when taken as a proportion of the overall costs, the proportional cost was greater for smaller farms by almost three times as much. With respect to the workforce, large farm enterprises had a much larger workforce of both full time and part-time staff. Smaller farm enterprises achieved slightly lower picking costs on average although this was not found to be significantly different.

Table 4-3 ANOVAs showing whether the means of the variable for the two farm categories are significantly different. The tabulated data describe the different economic factors on farm.

Farm variable	Small enterprise vs Large ent	ANOVA P value	Degrees of freedom
Proportion of income coming from strawberries (%)	22.2 65.3	< 0.001	38
Pesticides cost (£)	5,172 43,243	0.003	30
Proportion of costs spent on pesticides (%)	9.44 7.08	0.184	32
Plants cost (%)	12.3 16.7	0.079	32
Labour cost (£)	6,544 676,994	0.069	26
Proportion of costs spent on labour (%)	30.1 44.6	0.035	32
Infrastructure cost (£)	1,184 21,232	0.019	26
Proportion of costs to infrastructure (%)	8.1 2.9	0.054	32
Full time staff on strawberries[16] (people)	0.34 9.98	0.030	38
Casual workers on strawberries (people)	5.64 169.45	< 0.001	38
Tonnes harvested per picker	5.449[17] 4.626	0.514	29

[16] This was calculated by using the proportion of business income coming from strawberries and multiplying it as a percentage with the full-time or casual staff compliment, to determine how much of the staff contribute to the strawberry part of the business.

[17] In small farm enterprises, the owner or family members are involved in picking fruit, thus to take this into account they were included in the workforce.

4.3.3.1.1. Sales and marketing

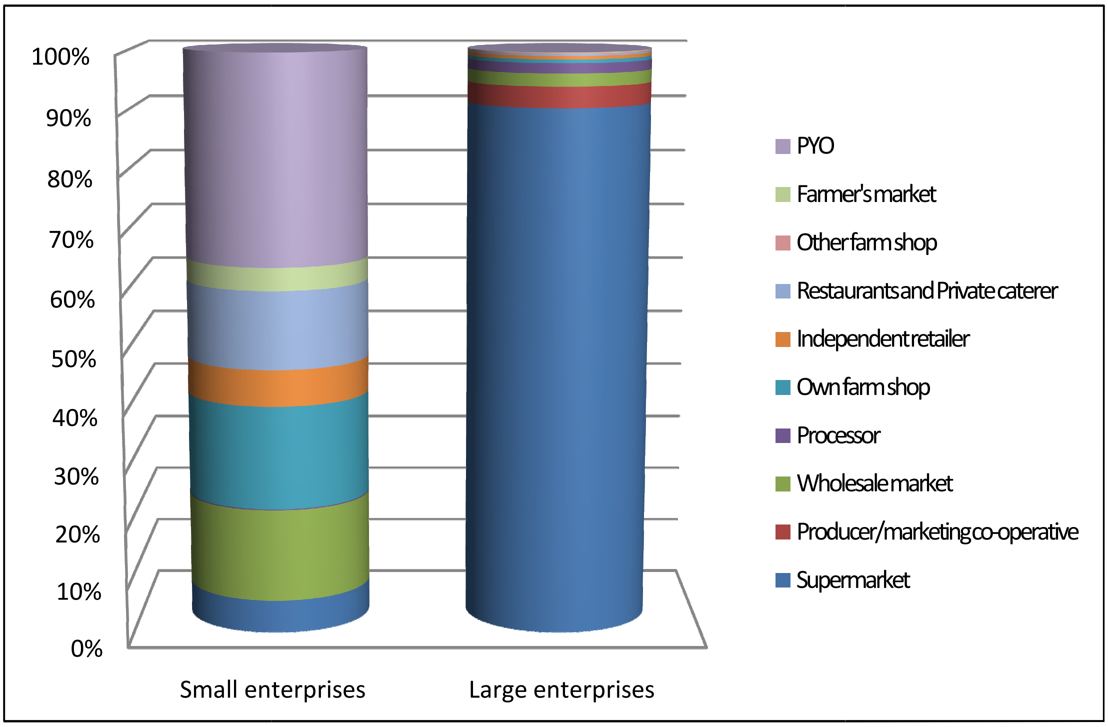


Figure 4-10 Market outlets for strawberries (by proportion of overall weight) grown in the two farm categories.

The two farm categories had completely different markets, as can be seen in Figure 4-10. The largest market outlet for large farm enterprises was supermarkets, which took up just over 90% of their produce. Small farm enterprises, on the other hand, sold less than 6% of their crop to supermarkets, with most of their sales being through Pick-your-own (PYO over 36%) or their own farm shops (around 17%).

Growers selling their crop to supermarkets also have to follow a number of standards and regulation including:

1. They have to follow the Assured Produce Scheme.
2. They have to be able to supply fruit on a constant and regular basis and not be dependent on the weather, necessitating protection of the growing crop.
3. They have to grow fruit according to a class category, with only Class 1 fruit going to supermarkets.

Prices are set in three different ways. The first is the predominant mechanism used by large farm enterprises. In order to sell their strawberries to supermarkets, they need to be members of, or affiliated to, a marketing organisation which deals directly with the supermarkets (except in the case of a small number of large farms that deal directly with the supermarkets). Prices are negotiated between a representative of the marketing body and the supermarket. The following is a quote from a marketing organisation

"We negotiate on a weekly basis for the following week. Retailers generally try and buy at the lowest possible levels at all times. But in the UK we agree a programme with most of our retailers on an advance basis, and with some we categorically manage the sector, so we're very involved in a detailed planning process for the marketing of their offer." KS1

The second is the main method used by small farm enterprises. The trend is to set the price themselves, or sometimes in negotiation with the retail point that they are selling to. In this situation, the grower has a greater input into setting the price and almost always obtains a higher price per kilo than that obtained through marketing organisations. They often sell their crop with no distinction in price between first and second class, and some growers even process the inferior quality crop and sell it as jams from their own farm shop, or through other local or regional shops.

The third mechanism is used by both types of strawberry farms and is the least preferred method of sale for both farm categories - the wholesale market. In this case, the wholesaler determines the price depending on the size of the market that week and on the quality of the product, but in most cases offers very low prices, sometimes being at a loss to the grower. The growers that sell to wholesale markets only sell their excess product which they were unable to sell through other means, or the product was of an inferior class for supermarket standards such as second class crop. Sometimes, the prices obtained at the wholesale market are so low that some large farm enterprises prefer to throw their second class crop away, since the returns are not high enough to cover picking and packaging costs. Nevertheless, those that do sell in this way use the wholesale markets at Glasgow, Manchester, Leeds or Gateshead for Scottish growers, and else London and the south of England for growers in Kent.

Despite the distinct separation of markets between the two farm-size categories, there are some apparent overlaps. This creates friction between the small and large farm enterprises and pressure especially for the small farm enterprises, since their alternative markets are quite small, catering for around just 10% of all strawberry sales in the UK. As one small grower said:

"The supermarkets this year have kept strawberries on promotion for most the year and the guys selling strawberries to them haven't been getting £1 a 1lb. They're driving these guys down the food chain to the little minnows like me rather than giving them a decent amount of money that keeps them happy. They hurt my business but I don't really see how it benefits their business." SG7

Of the farms encountered during the case study interviews, those supplying supermarkets were affiliated with one of 5 marketing bodies (Table 4-4). Other farms that sold directly through their own farm shop, PYO or local shops or markets were independent.

Table 4-4 Number of farms in Kent and Scotland affiliated to the different marketing bodies.

Marketing body	Kent	Scotland	small farm enterprises	large farm enterprises	Total
Angus Soft Fruit		7		7	7
Berrygardens	7	6	2	11	13
Berryworld	1	2		3	3
Summerfruit Company	6		3	3	6
First Class Fruits		1	1		1
None	6	6	13		12

Not surprisingly, small farm enterprises focused their sales locally whilst large enterprises had a national and sometimes regional focus (Figure 4-11).

Most of the farms grew other crops, as can be seen in Figure 4-12. Only 13% of the growers grew just strawberries. Moreover, almost all of the growers had been involved in the industry for at least two decades, averaging 32.3 years experience in the industry per grower (median 25 years). The farms have also been using the same marketing methods for at least the last decade, with large enterprises selling to supermarkets for the last 15 years on average (median was 12½ years), and small enterprises keeping the same outlets for even longer, approaching 20 years on average (median 15 years).

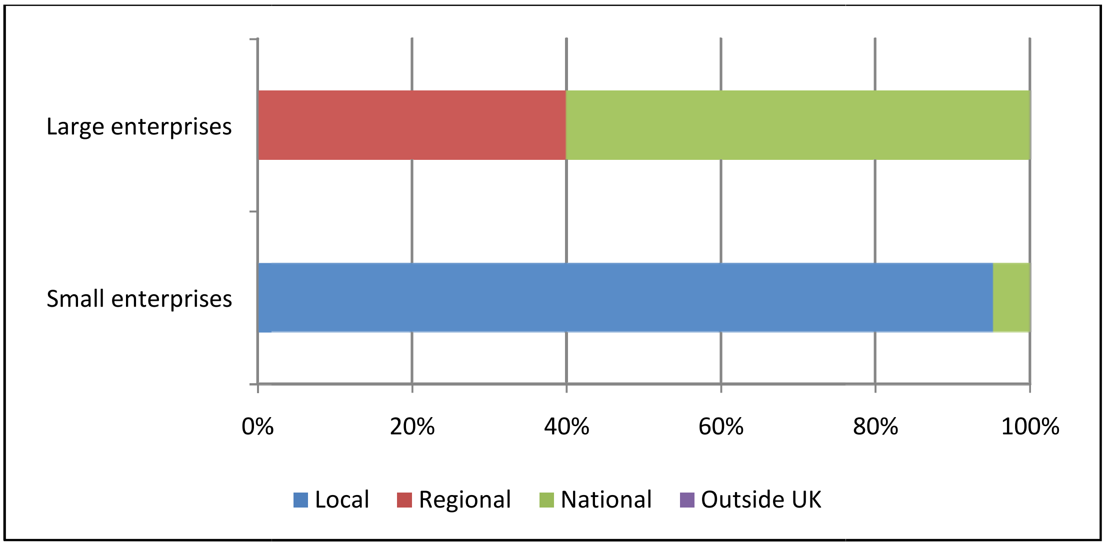


Figure 4-11 The focus of sales of the two farm categories

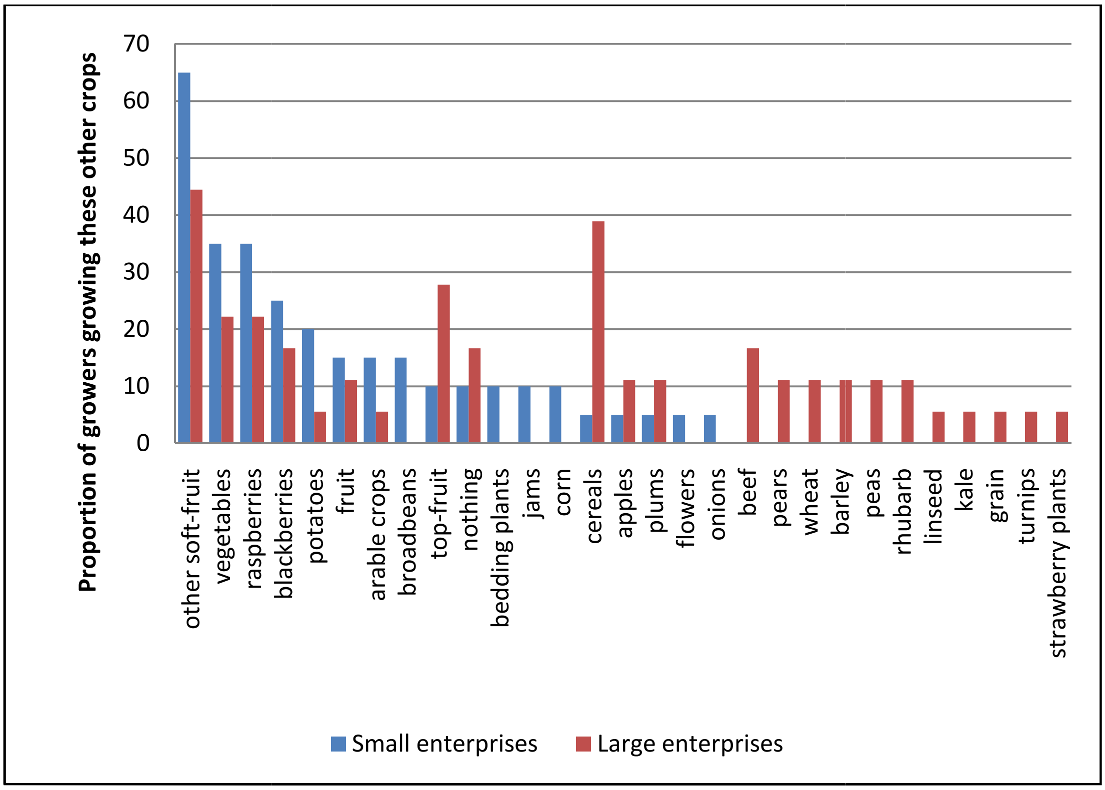


Figure 4-12 Other crops or business activities farms were engaged in.

4.3.3.1.2. Future developments

The sector has changed in its structure in the past 10 to 20 years. Apart from increasing the area of land under protection, the larger enterprises have increased in size while smaller strawberry enterprises have reduced their production of strawberries (Figure 4-13).

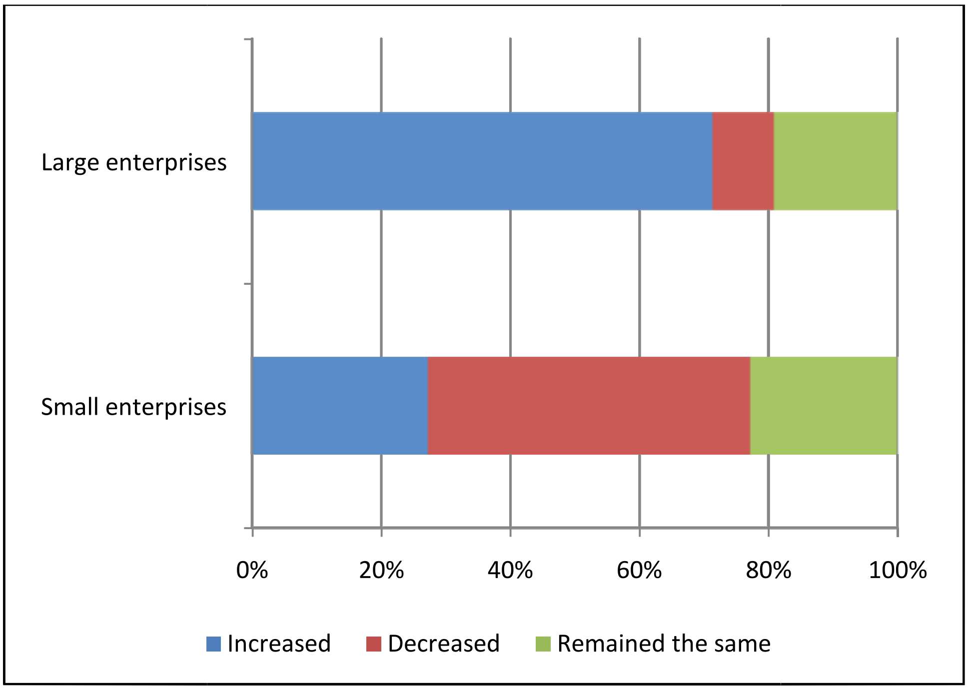


Figure 4-13 Change in area of land used for strawberries in the two farm categories over the last ten years.

When asked about the future (Figure 4-14), just under half of the large enterprises were planning to increase their production yet further, whilst almost 60% of the smaller enterprises were planning to remain the same size.

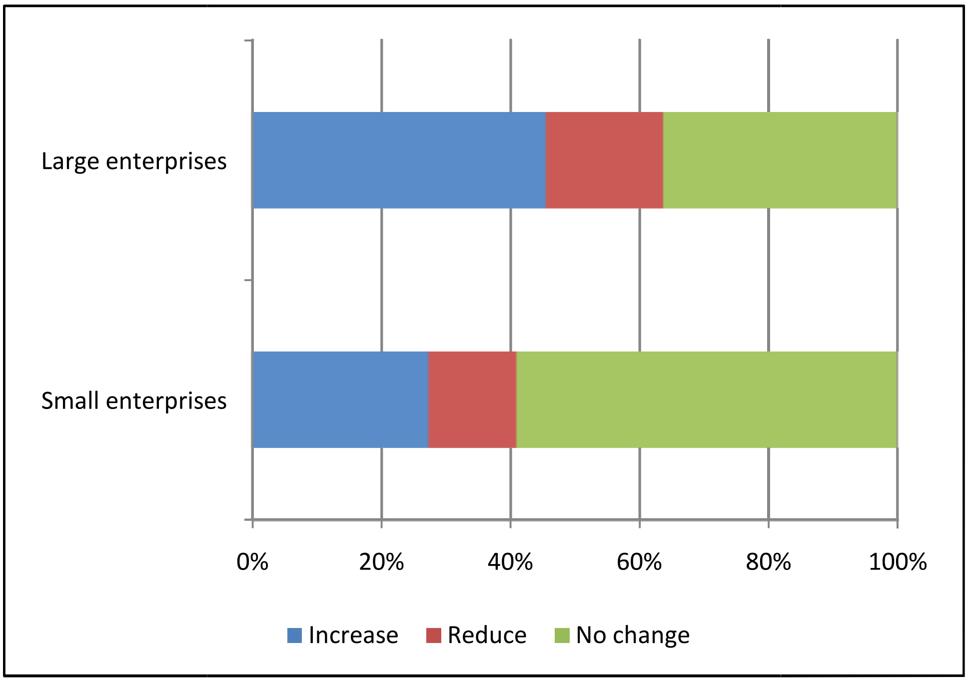


Figure 4-14 Predictive changes to production.

4.3.3.2. Influence of production systems

Three main production systems are used in the strawberry industry. These are:

- Open ground cultivation: strawberries are planted in the ground and are not protected by polytunnels. They may be covered by temporary protection such as fleece and cloches, but the plants spend most of the summer uncovered.
- Plants planted in the ground and covered by polytunnels.
- Plants grown in substrate in bags on tabletops. Everything is under tunnels. In some farms, the substrate bags are on the ground, although this is not that widespread amongst farms.

Glasshouse production was also encountered, but this tends to be a minority within the industry and is considered as a speciality of early production.

With the mixture of qualitative and quantitative data available from the social science study, the farms were divided into three categories according to production methods: plants grown in the ground, on substrate, and mixed systems. For the scope of this study, ground systems are defined as those where the crops are growing in soil, either in open fields or under protection. Substrate systems are those systems where the crops are growing only in tabletops. The third category of ‘mixed systems’ use both systems.

Insufficient data were available to know the exact proportion of substrate to ground production in the farms using mixed systems. This category encompasses a sliding-scale of ground to substrate cultivation, which could tip from one side of the scale to the other across the different farms. Thus, for this reason, the mixed production category was not considered in further detail in this chapter, and only the ground and substrate systems were analysed on their own merits, whilst omitting the farms in the mixed category.

On testing for statistical differences between the yield of these two production categories, ground systems were found to have much lower yields (15.38 Tonnes Ha^{-1}) than substrate cultivation (26.75 Tonnes Ha^{-1}) at an F-value of 0.01 (from a one-way ANOVA). To investigate this further, the production categories were further divided into two according to whether it was a small or a large farm enterprise (Table 4-5). Whilst farms using substrate systems obtained consistently higher yields in both farm size categories, the main significant difference was between yields obtained between small farm enterprises with ground and substrate cultivation.

Table 4-5 A two way ANOVA testing for differences in average yield obtained from the two different production systems across the farm size categories. Categories which are significantly different have different letters in brackets.

Farm size category	**Production system (Av. LSD = 11.91)**	
	Ground	Substrate
Large	17.26 (ab)	25.51 (abc)
Small	13.67 (a)	31.67 (c)

4.3.3.3. Structure of the supply chain

The three level supply chain within the strawberry sector consists of suppliers, growers and the retail sector. In large farm enterprises, extra levels exist including a Producer Organisation (between the suppliers and the growers) and a Marketing body or organisation (between the growers and the supermarket chain). The marketing body can sometimes, but not always, be closely affiliated with a PO, and in the case of a few POs, grower members have no option but to be a member of the marketing body to which the PO is affiliated.

These extra levels within the large farm enterprise category are only recent introductions, having emerged in the last 20-30 years with the introduction of cooperatives. The first cooperative that was involved in strawberry production was set up in the early-1970s. By the 1980s, some supermarkets preferred to deal directly with the cooperative, which initially were composed solely of growers. Subsequently, the cooperative employed the services of a marketing company to facilitate fruit sales. This system was so popular with supermarkets that they started to deal more directly with cooperatives. The cooperatives in turn sold more fruit and gradually became bigger as more growers found it profitable to be within such an organisation. By the early-1990s there were about 10 organized marketing groups representing about 60% of output (Carter *et al.*, 1993).

The introduction of the fruit and vegetable PO scheme in the 1990s meant that a number of the soft-fruit cooperatives were suitably structured to take advantage of these schemes. This enabled their grower members to become eligible to buy machinery and polytunnels that would help restructure the sector.

Financial support was provided by EU funds for the sector. In 2008 alone, the seven main producer organisations involved in the strawberry industry obtained just over €10.5m of EU funds (Table 4-6), most of which was used to support capital programmes such as construction of polytunnels, and provision of tabletops and other equipment for their grower members.

Table 4-6 EU funds provided to 7 main Producer Organisations in 2008. Source: farmsubsidy.org

Name of Producer organisation	EU funds 2008
KG Growers PO	€3,981,080
Berryworld PO	€2,441,350
Fruition PO	€1,564,420
Angus Growers PO	€889,556
Asplins PO	€838,828
Mockbeggar PO	€660,989
Wyefruit PO	€193,395

4.3.3.3.1. Inputs

Pesticides, fertilizers, machinery and equipment are usually sourced locally (nearest town or agricultural services shop) or within the region for both small and large farm enterprises. Labels and packaging within small farm enterprises are sourced through a local distributor (Figure 4-15), whilst for large farm enterprises (Figure 4-16) it can either be sourced through the distributor, the PO or, in case of very large farms, directly through the manufacturer. Polytunnels are always sourced within the UK, mostly through direct negotiations between the grower and the supplier. The suppliers in turn order them either directly from their own manufacturers or else through a subsidiary company abroad. Some of the growers with large strawberry enterprises also buy their polytunnels directly from their PO.

Plants are obtained through a number of means:

1. From a UK based nursery that produces its own plants or may also import them. This is the preferred option for small farm enterprises.
2. From a UK based nursery that does not grow its own plants but imports them from abroad from a number of sources such as the USA, Netherlands, Italy and Spain.
3. From overseas nurseries (some large farm enterprises buy their plants directly, especially if they are buying large volumes of plants).
4. From POs, some of which have their own protected varieties, which can only be used by growers that are members of that PO. These plants are usually grown abroad, and imported into the UK.

Growing media (substrate or bags, as growers often refer to them) is usually bought from UK companies which import them from abroad, either as peat from Ireland or as coir from India or Indonesia. Tabletops are mostly bought from the same companies that sell polytunnels; however, some growers also build their own tabletops.

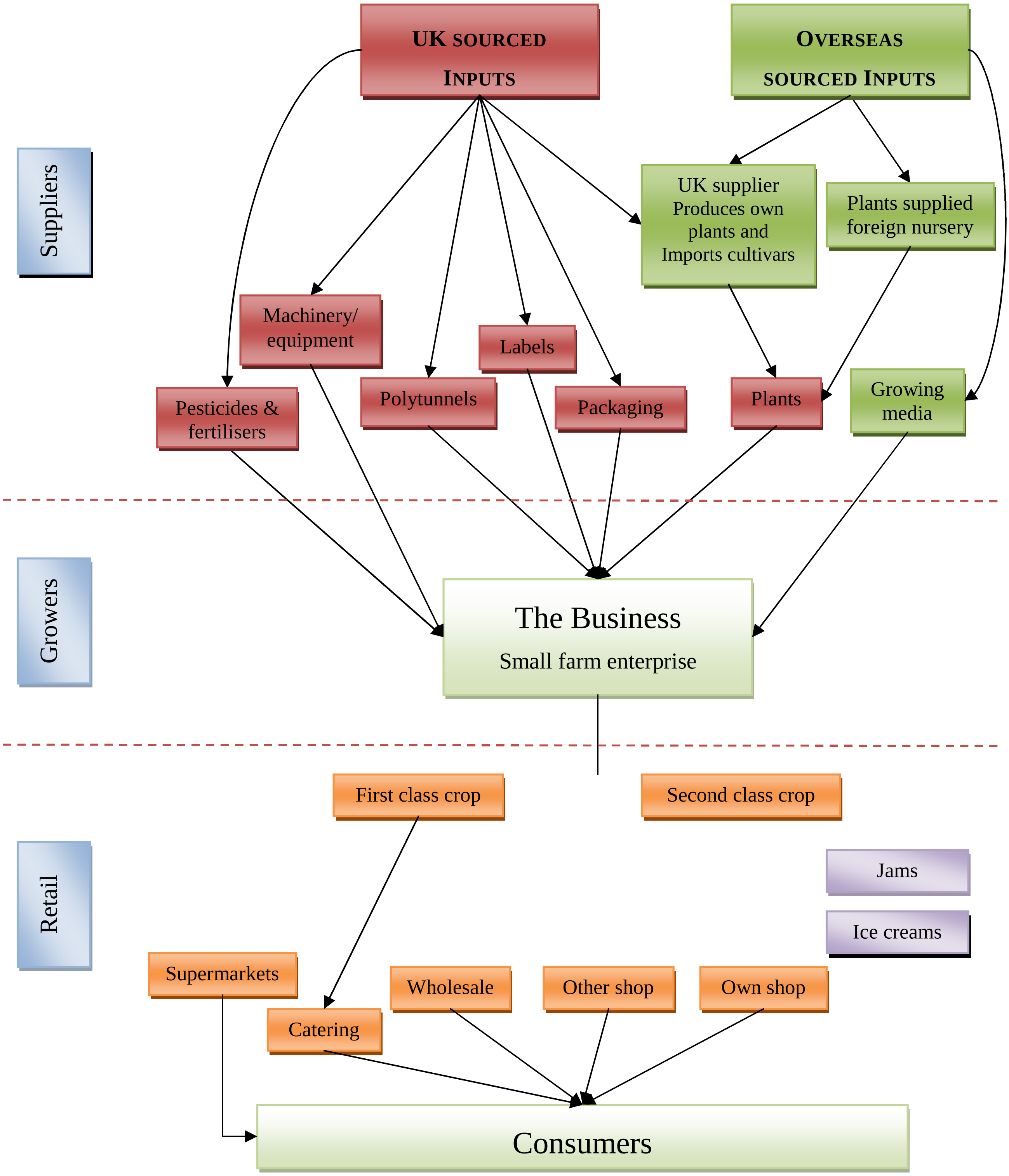


Figure 4-15 Supply chain diagram for small farm enterprises. More of the inputs are from locally sourced or UK sourced agents or businesses. The retail part of the supply chain is much more varied and involves different outlets

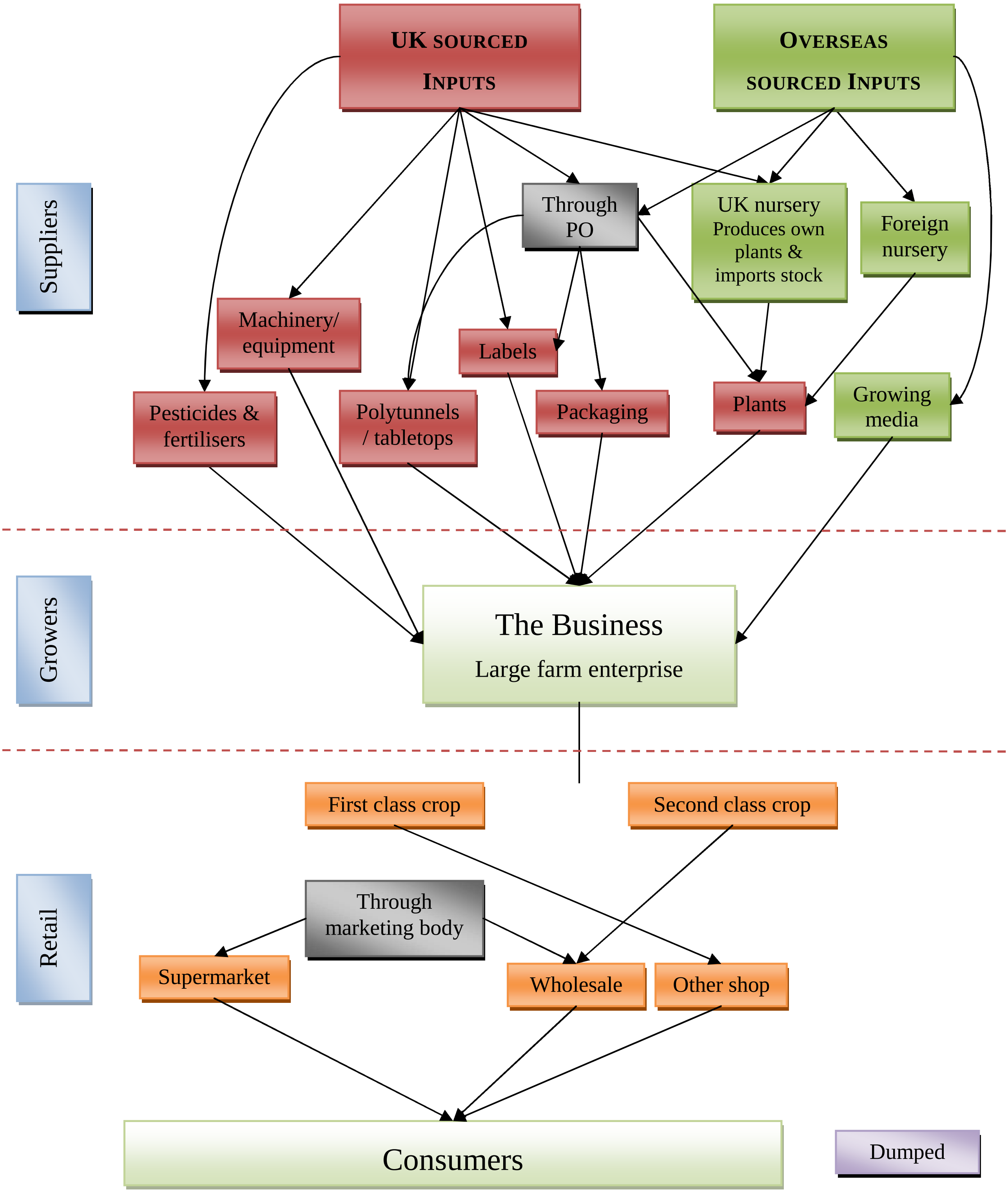


Figure 4-16 *Supply chain diagram for large farm enterprises.*

4.3.4 Discussion - Transformation of the strawberry industry

The structure and shape of the strawberry industry are intrinsically linked to the way the businesses sell their crop. The requirements of the two predominant markets have forced farms to adapt and change in order to fit their business plans to the market's requirements. On one hand, the supermarket chains have their own requirements, which farm businesses need to comply with (Fearne and Hughes, 2000). These include a number of regulations and standards (Dobson, 2005), such as minimum levels of pesticide usage, type and shape of fruit, time of the year when they are brought to the market, how they are grown and even how and in what they are packed and transported to the market. On the other hand, the market for the smaller farm enterprises survives because of the existence of a clientele that is looking for an alternative to buying supermarket grown strawberries (Holloway *et al.*, 2007). In fact, these farms often do not use polytunnels because it puts-off their clients who are looking for a product grown in a more traditional way, out in the open field.

The situation was not always this way. As Carter *et al.* (1993) reported in the early 1990s, only 30% of fresh strawberries were being sold through supermarkets. Prior to the 1970s and 1980s, most of the UK strawberry production was sold either through the wholesale market, ending up in supermarkets, other shops, or the fruit processing industry, or else sold as pick-your-own (PYO) fruit directly from the farm (Beech and Simpson, 1989).

There were also very few strawberry specialists firstly, because of the inter-annual variability in crop yield, which was very highly weather dependent (see Figure 2-12), and secondly, because of the length of the season, which until the introduction of everbearers was only limited to a six week window (Beech and Simpson, 1989).

In the 1980s, a number of UK based research centres, in particular HRI at East Malling and the Scottish Crop Research Institute at Invergowrie, were developing a variety of cultivars that would help extend the season to potentially five months (Taylor *et al.*, 1993, Simpson *et al.*, 1997, McNicol *et al.*, 1997). Until then, very few growers used any sort of protection, which consisted of cloches and French tunnels. These were small and low, and most growers were afraid that they would be blown away by the wind. The introduction of Spanish tunnels in the mid 1990s made the overall structure stronger, and the ability to raise the side vents meant that the humidity inside could be controlled and disease incidence lowered.

By the turn of the millennium, the cooperation between the supermarket chains and cooperatives, which by then had their own marketing bodies, was such that the two were building a yearly work programme together that would spread the crop throughout the season, thus maximising sales and minimizing waste (Fearne *et al.*, 2006). This provided an unprecedented growth in sales, providing an ideal market for growth in production. This was an opportunity for growers to increase their tonnage and to increase in size. However, by doing so they became entirely dependent on supermarket sales. Supermarkets controlled prices and limited the profit margins for growers (Dobson, 2005), thus the only way to increase their income was to become more technologically advanced and increase their volume (Rogaly, 2008). As a result, this led to expansion of a number of farms, particularly through their membership of a PO. As farm businesses increased in size, specialist businesses were created to support the sector and the strawberry sector gradually became an industry with specialist suppliers and specialist marketing bodies that dealt in turn with a dedicated soft-fruit “buyer” within each major supermarket brand.

Whilst a number of growers followed the path of restructuring into larger and more efficient farms, many preferred not to follow that route and avoid dealing with supermarkets. However, the increase in dominance of supermarkets in the last 20 years has meant that the market share for the non-supermarket growers or, as they have been labelled for the purpose of this study, the small farm enterprises, has decreased from 70% in the early 1990s to around 10% currently. This supermarket dominance is echoed throughout the fresh food industry and by 2006, the largest four supermarket chains controlled over 70% of the UK fresh produce market (Dibb *et al.*, 2008). For strawberries, this decrease has also been driven by the collapse of the fruit processing industry which by the late 1980s represented a quarter of the total fruit output (Beech and Simpson, 1989).

In spite of the decrease in their market share, small farm enterprises on the whole prefer not to trade with supermarkets. In doing so, they do not have to follow a number of standards. Their clients are usually not interested in class categories. As a consequence, they do not classify their fruit and usually sell their entire crop at the same price throughout the year, almost always being substantially higher than that obtained by large farm enterprises. An ability to set their own prices has helped them survive the lower yields since they can afford to lose some of their crop. Nevertheless, these farms tend to have smaller resources and are highly susceptible to any impacts or threat from the market or climate. They have smaller farms and, their smaller volumes of produce mean that they have a smaller turnover and less money to invest in technology. In fact, whilst their expenditure on infrastructure was on average 18 times less than that of the large farm enterprises, proportionately it was almost three times more. This phenomenon is mirrored in other agricultural sectors, including the hops and potatoes, where the accumulation of capital resources in successful farms enabled them to create the capital by which further expansion could be financed (Harvey, 1963) or survival maintained (Ilbery and Maye, 2008).

Moreover, not being part of a producer organisation makes small farm enterprises even more vulnerable, since they are not eligible to make use of EU funds to invest in the restructuring of their farm to adapt to current threats. This was a contributing factor to the demise of a number of growers that once grew strawberries on a small scale. Of those that still grow strawberries, half have decreased the area of their crop. The size of their market (10% of total UK sales) is another contributing factor to this decline. Whilst some farms do well, due to their being well connected to the market, others struggle. Their small volume does not make it feasible for them to transport the crop large distances to find a better market. In fact, most of them want to focus their sales more locally in the future, seeing more opportunities in local and regional sales. Notwithstanding all of these limiting factors, they survive because of the existence of a small alternative market of customers that insist in buying non-supermarket strawberries and preferring to buy local (Ilbery and Kneafsey, 1998, Ilbery and Maye, 2005). This phenomenon has been seen in other agricultural sectors (Holloway *et al.*, 2007), and is one of the drivers behind the emergence of the so-called post-productivist transition (Ilbery and Watts, 2003).

Location was another factor that could affect the survival of these small farm enterprises. Small farms in remote areas, away from an urban centre, were seen as being more risky as they had to expend a greater proportion of resources in getting their crop to the market (Blair, 1980).

Some growers also think that the UK strawberry market is at carrying capacity and may bring more of these pressures in the future. Periods of overproduction or low demand due to bad weather encourage supermarkets to offer product promotions, forcing marketing bodies and their growers to lower their prices and reduce profit margins even further. This will put at risk the farms that are struggling with debts and extra costs, and will result in fewer growers, with the survivors taking up the sales of other farms that have closed down or changed crop. Thus it will be the large farms running on a greater profit margin, greater financial resources, and having higher yields that will survive in the future, since they will be better equipped to respond to changing market requirements.

4.4. PLANT DISEASE AND ITS INFLUENCE ON THE BRITISH STRAWBERRY SECTOR

In this section, the parts of the postal questionnaire and semi-structured interview that focused on plant disease will be analysed. First, the importance of plant disease to growers and the relative risk it poses to the business is analysed. This is followed by a description of the methods used in farms to identify disease, and in turn by an assessment of the prevalence of different diseases on strawberry farms in the UK. Finally, the management of plant disease is assessed. This is then followed by a discussion.

4.4.1 Results - Plant disease

All growers were found to have problems with plant disease. Almost 50% of them described the disease situation as a 'continuous battle', whilst 40% described it as being a 'regular' phenomenon. Crops grown in large farm enterprises were more frequently affected by disease, as can be seen from Figure 4-17. Growers in Kent and Scotland had crops that were generally similarly affected by disease, with the exception that slightly more growers in Scotland were only 'occasionally' affected.

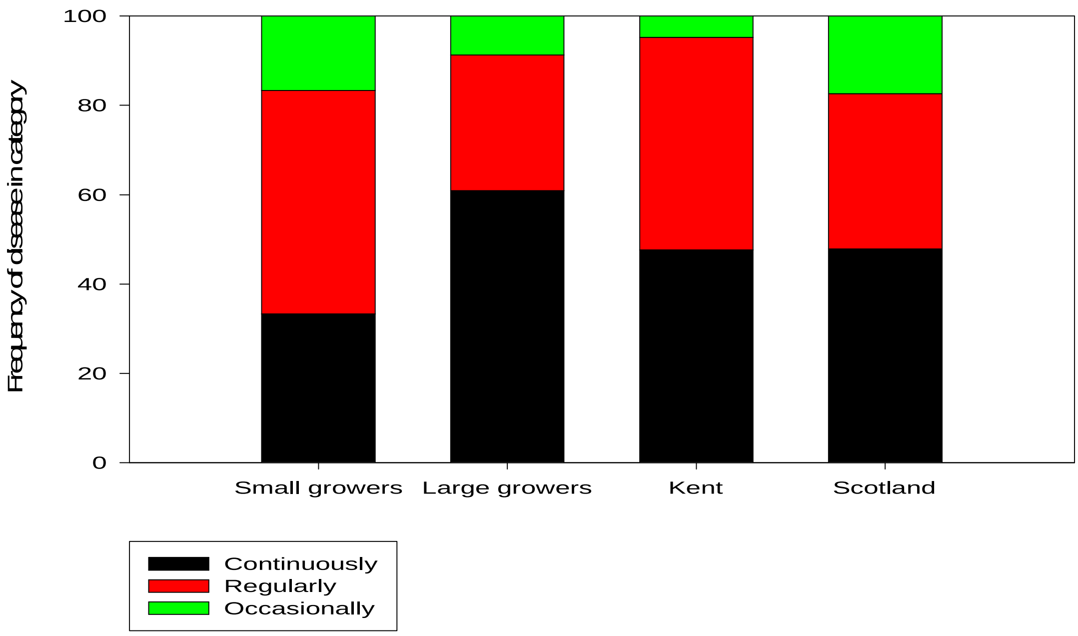


Figure 4-17 Proportion of growers considering disease as being a continuous, regular or occasional problem.

Almost 68% of large enterprises considered plant disease as a high risk to their farm compared to only 28% of small farm enterprises. Inversely, twice as many small farms considered plant disease as a low risk (Figure 4-18). More Scottish farms also considered plant disease to be a low risk compared to farms in Kent.

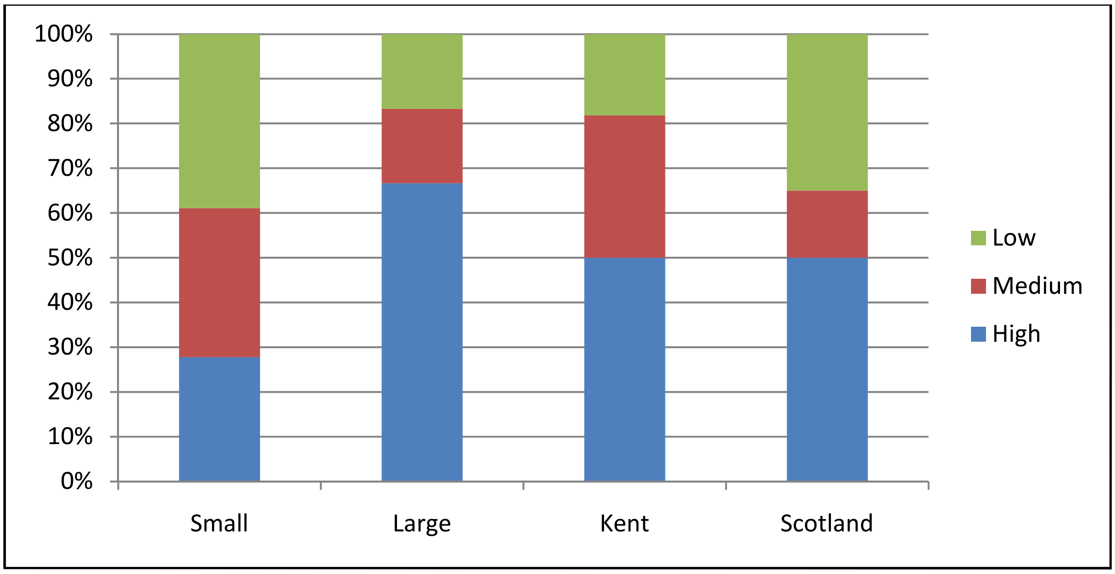


Figure 4-18 100% stacked bar chart showing plant disease as a risk according to the size of enterprise and region

When divided by production system, substrate production was found to be least susceptible to plant disease, with fewer growers within that category ranking plant disease as a high risk on their farm (Figure 4-19).

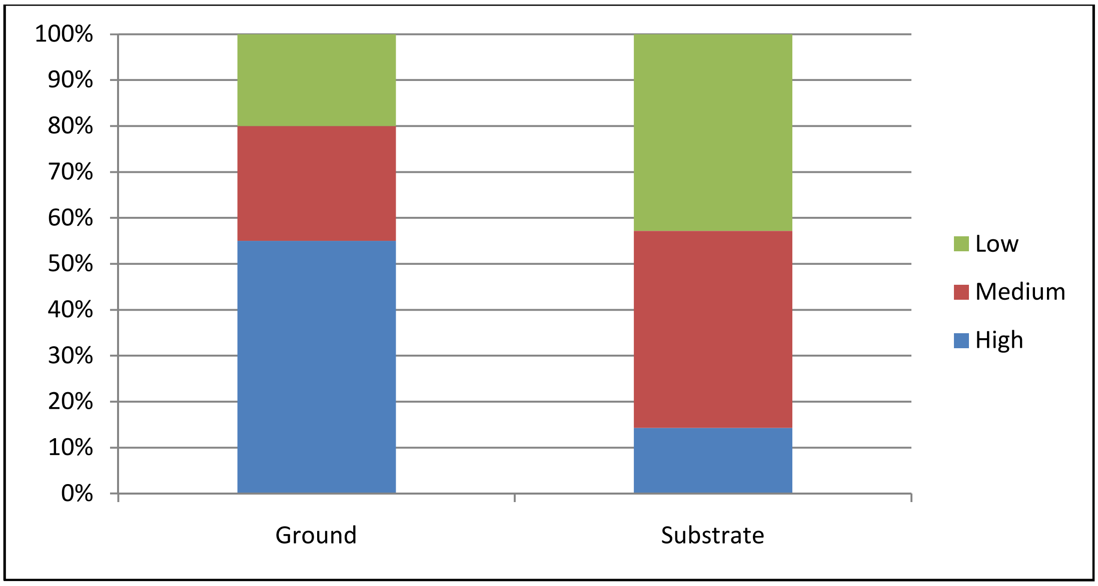


Figure 4-19 100% stacked chart showing plant disease risk in different production systems

4.4.1.1. Identifying plant disease

Few growers identify and deal with plant diseases independently (Figure 4-20). Only around 20% of all growers identify plant diseases themselves, with this figure being less for growers in large farm enterprises. Approximately 90% of large growers use the services of an agronomist, compared to 70% in small farm enterprises. Regular crop walking is used to identify disease outbreaks, with many growers and their agronomists walking the crop on a weekly to fortnightly basis.

The agronomists either belonged to a Producer Organisation (POs) or they were independent and were contracted by the growers themselves. Nearly 60% of the growers were visited by agronomists through their POs as a complementary service (this service is offered namely by KG Growers and Angus Growers). Almost two-thirds (64%) used independent agronomists. A third of the growers (33.3%) used the services of more than one agronomist, who visited the farm in turn, usually inspecting different varieties, depending on whether or not they worked for a PO.

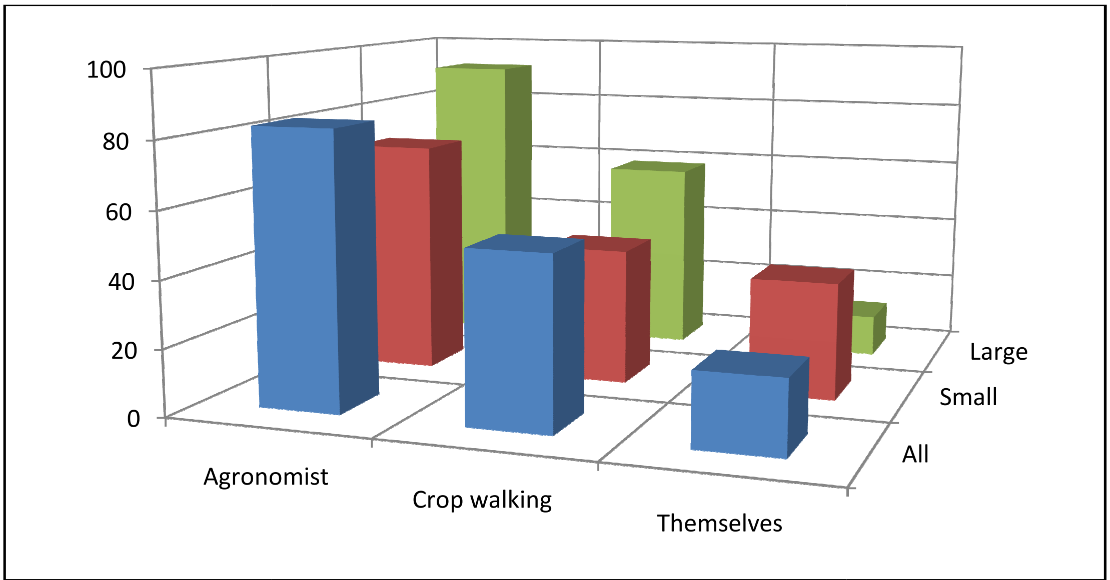


Figure 4-20 Vertical bar chart describing how growers identified plant disease. Crop walking is a procedure during which the grower or their representative walks the crop together with the agronomist to identify potential disease outbreaks through the presence of early symptoms.

4.4.1.2. Disease prevalence

Botrytis cinerea and powdery mildew were by far the two most common diseases, being reported on over 80% and 65% of the farms (Figure 4-21). Slight differences were observed between small and large farm enterprises. Powdery mildew, red core, Verticillium and vine weevil were more common in large farm enterprises, whilst black spot (*Colletotrichum acutatum*) was more common with small growers (Figure 4-22). *B. cinerea* occurred at the same rate irrespective of farm size.

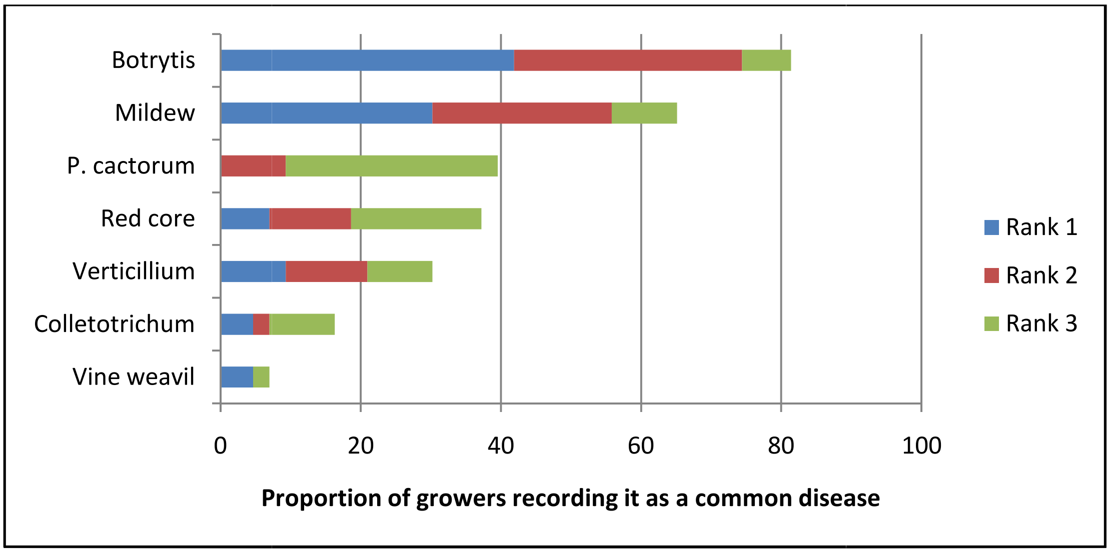


Figure 4-21 Horizontal bar chart showing the proportion of growers listing the diseases as being common on their farm. The growers also ranked three diseases according to which was the most common, starting with Rank 1 = the most common Rank 2= second most common etc

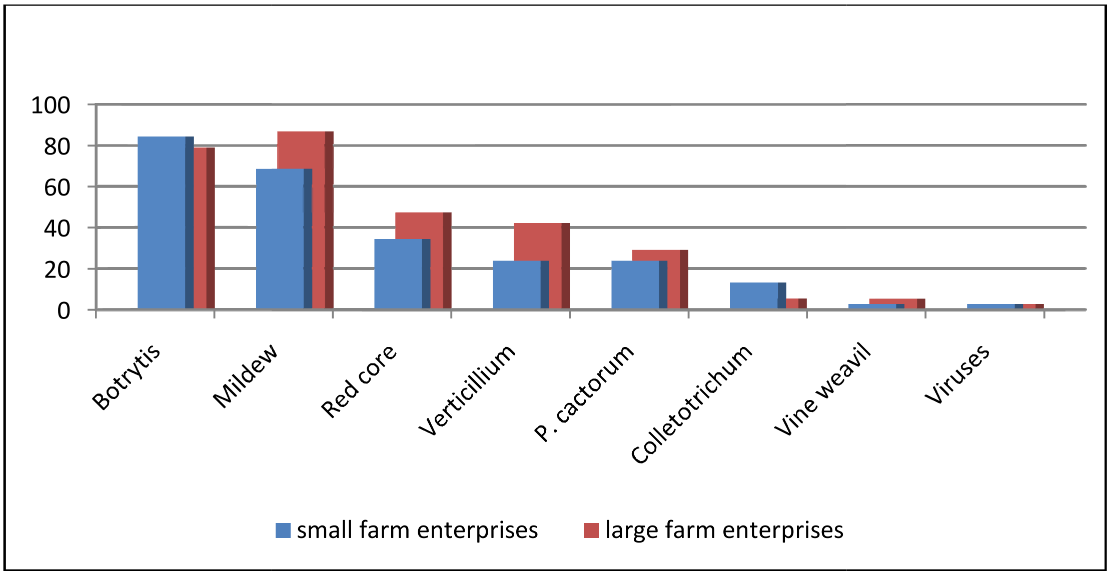


Figure 4-22 Vertical bar chart showing the proportion of growers recording the corresponding diseases as being common on their farm, divided according to farm size.

When disease frequency was analysed by production system, powdery mildew was more common in substrate than *B. cinerea*, whilst *B. cinerea* was more common in ground production (Figure 4-23). One Scottish grower explained:

"I think we may be in a worse position than people using tabletops (substrate), just because our fruit are closer to the source of free water. If there's constant rain there's high humidity in the tunnels and we get botrytis all the time. We might have to think of another way of growing the crop." SG15

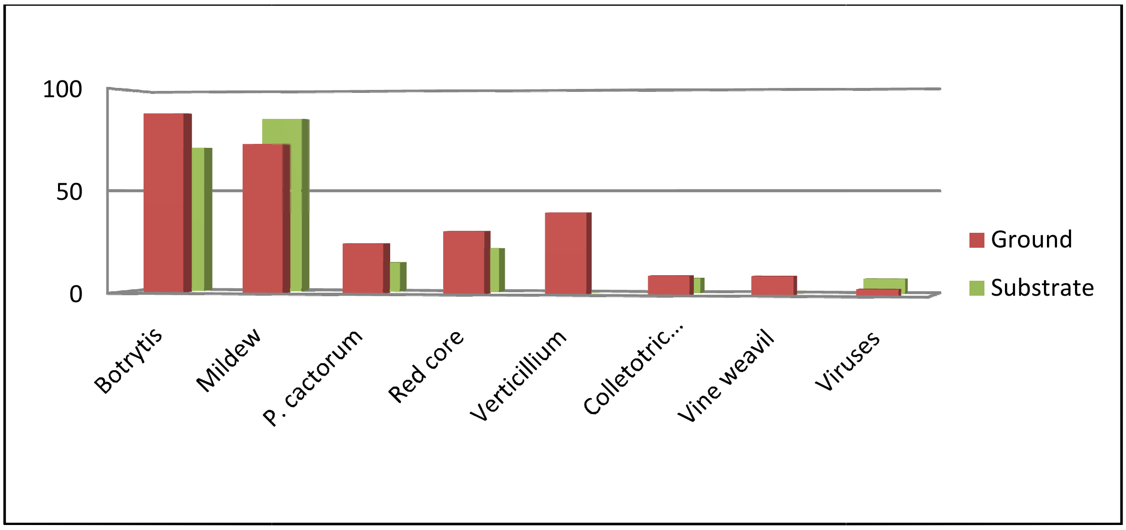


Figure 4-23 Vertical bar chart showing the proportion of growers recording the corresponding diseases as being common on their farm, divided according to the production system.

Verticillium wilt was absent in substrate production, and *P. cactorum* and red core were least common in substrate production. Powdery mildew and *B. cinerea* were actually the only two widespread diseases in substrate production.

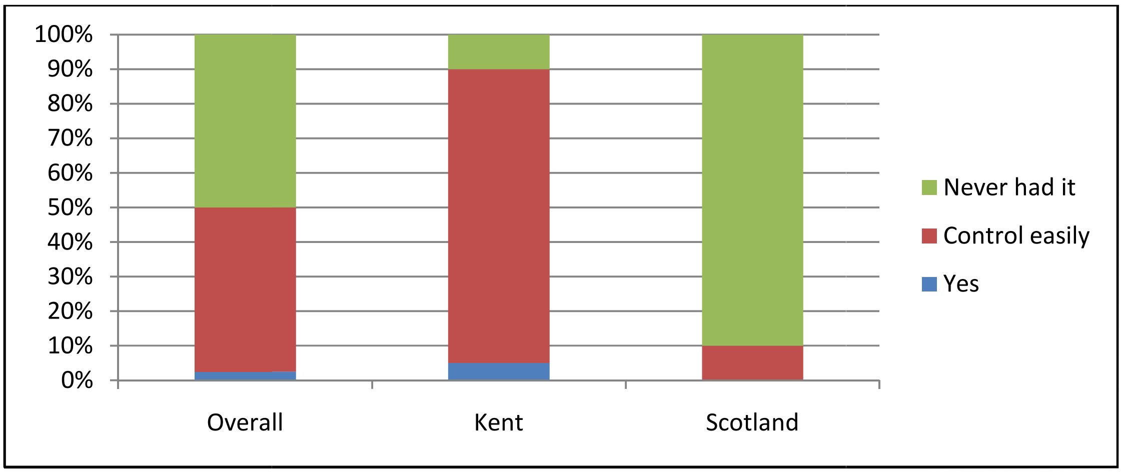


Figure 4-24 Stacked bar chart showing the proportion of growers believing black spot to be a problem.

Black spot was found to be a problem by less than 3% of the farms, with over 50% stating that they never encountered it on their farms (Figure 4-24). The remaining c. 46% said that it can be easily controlled. Most of the latter were farms in Kent that had been infected in the past during the black spot epidemic in the 1980s and 1990s. More than 90% of the farms in Scotland had never had the disease on their land.

4.4.1.2.1. Fruit loss

B. cinerea and powdery mildew were again found to be the two diseases causing the greatest loss of crop, with Verticillium wilt, red core and *P. cactorum*, less prevalent. Differences were observed between small and large farm enterprises, with losses due to *B. cinerea* being more severe on small farms and powdery mildew being more severe on large farms. (Table 4-7).

Table 4-7 Average disease severity in 'good' and 'bad' disease years on small and large farm enterprises. Severity in this case was taken as a measure of fruit loss due to disease. In this case, the growers were asked to rank the disease according to attitude batteries, from 0 to 5, with 5 being the worst case scenario. This was done for both 'good' and 'bad' disease years.

Disease	**Disease severity year**	**small**	**large**
red core	good	0.7	0.6
	bad	2.0	2.4
black spot (*Colletotrichum*)	good	0.4	0.2
	bad	1.3	1.5
B. cinerea	good	1.0	0.7
	bad	3.5	2.9
powdery mildew	good	1.1	0.7
	bad	2.6	3.2
P. cactorum	good	0.6	0.5
	bad	1.8	2.4
Verticillium wilt	good	0.5	0.6
	bad	2.2	2.3
Mucor/Rhizopus	good	0.2	0.2
	bad	0.6	1.0
Viruses	good	0.3	0.1
	bad	0.6	0.8

With respect to production systems, *B. cinerea* was again worst for ground cultivation, causing the greatest loss in comparison to other production systems (Table 4-8). Powdery mildew was worse in tabletop production, as was *P. cactorum* and red core. Verticillium was only slightly worse in ground cultivation than in the other production systems.

Table 4-8 Average disease severity on 'good' and 'bad' disease years on farms using different production systems. The severity in this case was taken as a measure of fruit loss due to disease. In this case, the growers were asked to rank the disease according to attitude batteries, from 0 to 5, with 5 being the worst case scenario. This was done for both 'good' and 'bad' disease years.

Disease	Disease severity year	ground	substrate
red core	good	0.4	1.5
	bad	1.7	3.5
black spot (*Colletotrichum*)	good	0.2	0.0
	bad	1.7	0.8
B. cinerea	good	0.8	0.5
	bad	3.5	2.8
powdery mildew	good	0.6	1.3
	bad	2.5	3.5
P. cactorum	good	0.3	1.2
	bad	1.9	3.5
Verticillium wilt	good	0.4	0.7
	bad	2.5	2.2
Mucor/Rhizopus	good	0.2	0.2
	bad	0.7	0.8
Viruses	good	0.3	0.0
	bad	0.7	1.3

4.4.1.2.2. *Economic impact of plant disease*

When growers were asked to note which diseases caused the greatest economic impact on their farm, *B. cinerea* was seen to have by far the greatest impact on small farm enterprises (Figure 4-25). Verticillium wilt had the greatest impact on large enterprises. The other diseases ranked lower in terms of economic impact for these two categories.

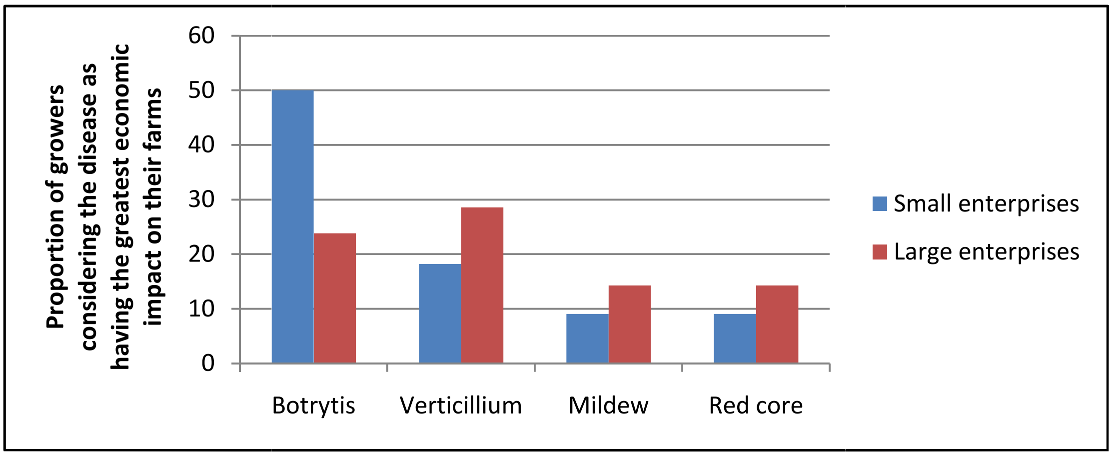


Figure 4-25 Vertical bar chart showing the economic impact of diseases on farm enterprises.

On analysing the data according to the production system, *B. cinerea* had the greatest economic impact on ground production, with Verticillium second (Figure 4-26). Powdery mildew was not an economic problem on such farms. In substrate production, powdery mildew and *B. cinerea* equally had the greatest economic impact.

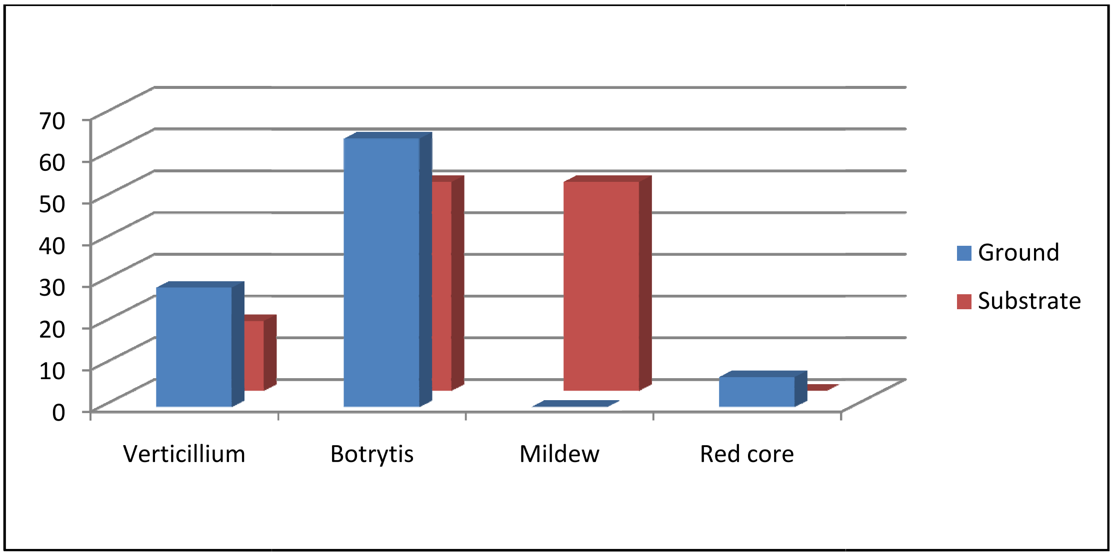


Figure 4-26 The economic impact of diseases on different production systems.

4.4.1.3. Disease management

Factors considered as contributing to disease susceptibility were ranked by growers (responses ranked in order with rank 1 being most important). Weather was found to be the most important factor for causing disease incidence in strawberries, with 88%

of growers recording it in their responses (Figure 4-27). It also obtained the highest number of top ranks, with just over half of the growers recording it as the most important factor. Use of a wrong variety, pesticide availability and growing the crop in the open field were all mentioned by at least half of the growers. When responses were analysed by farm size category, there was very little differentiation in the responses.

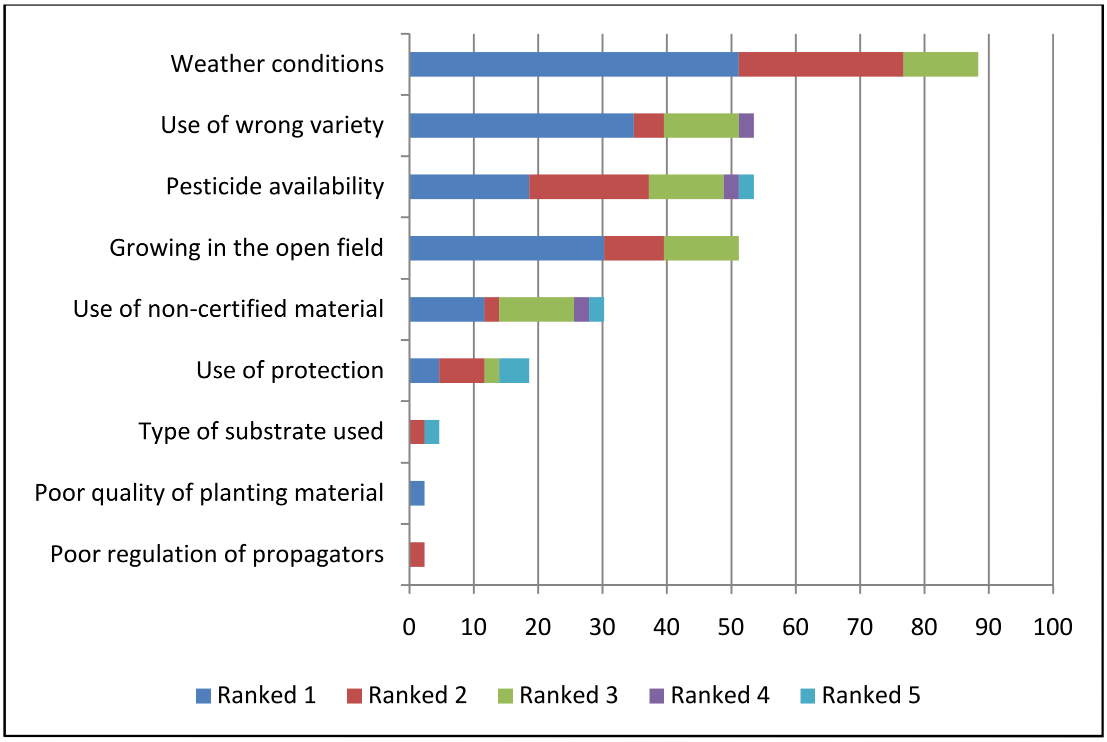


Figure 4-27 Stacked horizontal bar chart showing the factors considered as contributing to disease susceptibility.

In terms of the most effective ways of controlling or minimising strawberry disease, over 20 different responses were obtained from growers. Six broad categories of response were obtained (Figure 4-28), with the effective use of chemicals ranked most highly. The second most important category was a combination of precautionary methods that included good husbandry and cultural methods. Using appropriate ‘clean’ plants (i.e. disease-resistant, certified planting material) and using the correct cultivation methods were suggested by around 50% of the respondents. All farms used chemical methods to control plant disease. The main methods used are precautionary (prophylactic) sprays as part of a spray programme, coupled with additional sprays when disease symptoms are observed. Slightly more growers use chemicals upon evidence of disease symptoms. There was little difference in the way small and large farm enterprises used chemicals.

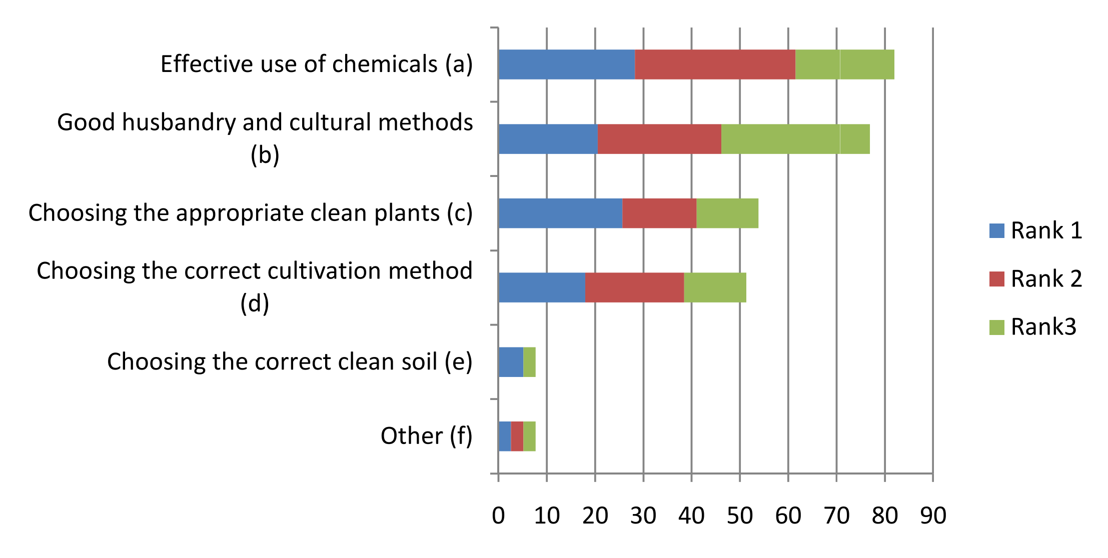


Figure 4-28 Ranked responses to the most effective ways of controlling plant disease. Letters in brackets are the symbol for the abbreviation of that category.

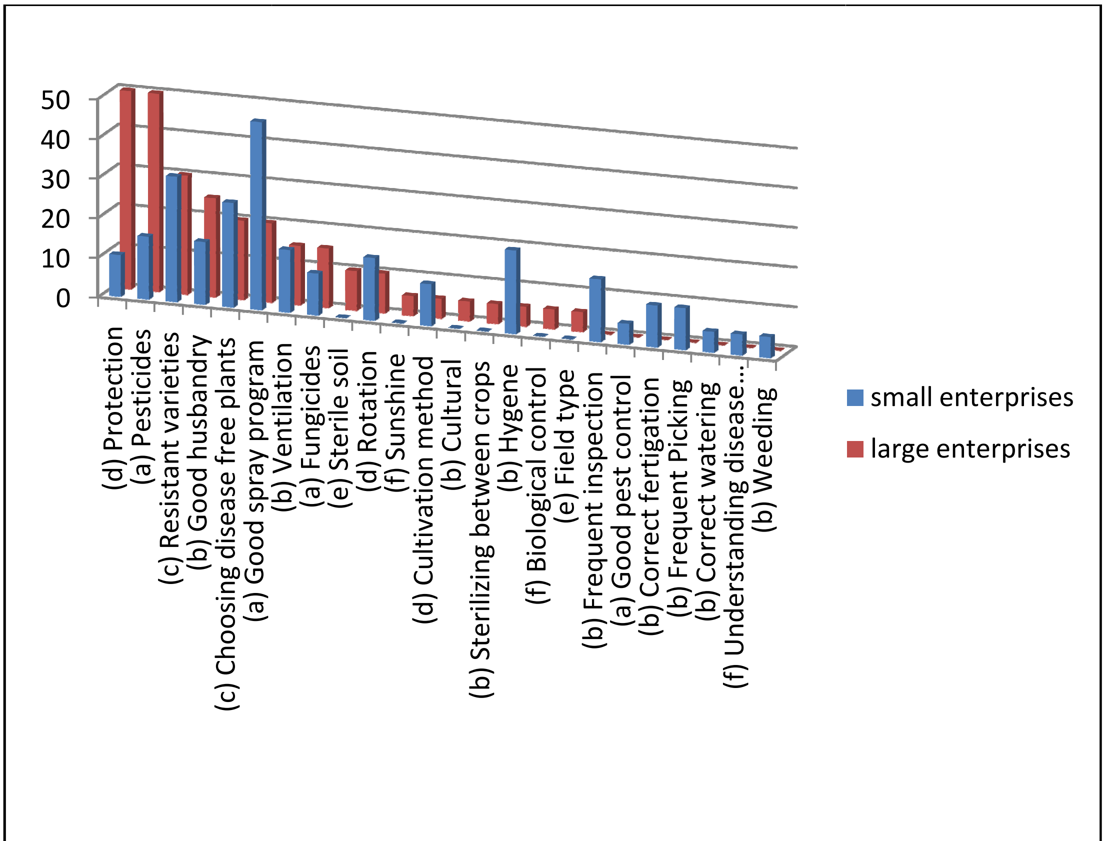


Figure 4-29 List of the most effective methods to control or reduce plant disease incidence as suggested by the two farm types. Letters in brackets are the broad categories to which these responses have been classified (refer to Figure 4-28). Data collected from the questionnaires.

The vast majority of growers (95%) had a disease management plan. This almost always involved the use of fungicides, mostly through a spray programme, but also through supplementary sprays when needed (Table 4-9). Crop walking was the third most common method used to identify and deal with disease.

Table 4-9 The proportion of farms in the respective categories that use one of the listed methods to deal with plant disease. Data collected from the case study interviews.

	small enterprises	large enterprises	all enterprises
Fungicides	88.9	100.0	95.2
Spray programs	77.8	95.8	88.1
Crop walking	38.9	58.3	50.0
Spray as needed	22.2	12.5	16.7
Cultural methods	5.6	16.7	11.9
Integrated pest management	0.0	12.5	7.1
Biological control or Organic	0.0	12.5	7.1
Purchase of healthy plants	11.1	8.3	9.5
Crop rotation	5.6	8.3	7.1
Predictive modelling	0.0	8.3	4.8

Differences between farm categories were only slight, with the largest being in the slightly higher number of large farm enterprises using alternative methods of control, such as Biological control, organic farming, IPM and crop walking.

4.4.1.3.1. Reliance on pesticides

High reliance of the sector on pesticides has resulted in an industry dependent on the availability of chemical means of combating plant disease. During the case study interviews, 82% of the participants suggested that changes in the Pesticides Directive had been a cause of concern. Of the growers interviewed, only 12% said that the changes would not affect them (Figure 4-30). One large grower said:

"Oh…. yes, we all know about that. It terrifies us. Absolutely terrifies us. Very, very serious problem. It's hitting us hard already. Chemicals we can't use anymore. Chloropicrin we've only got two more years for. That's why we're getting into bags so we don't need to use chloropicrin." KG3

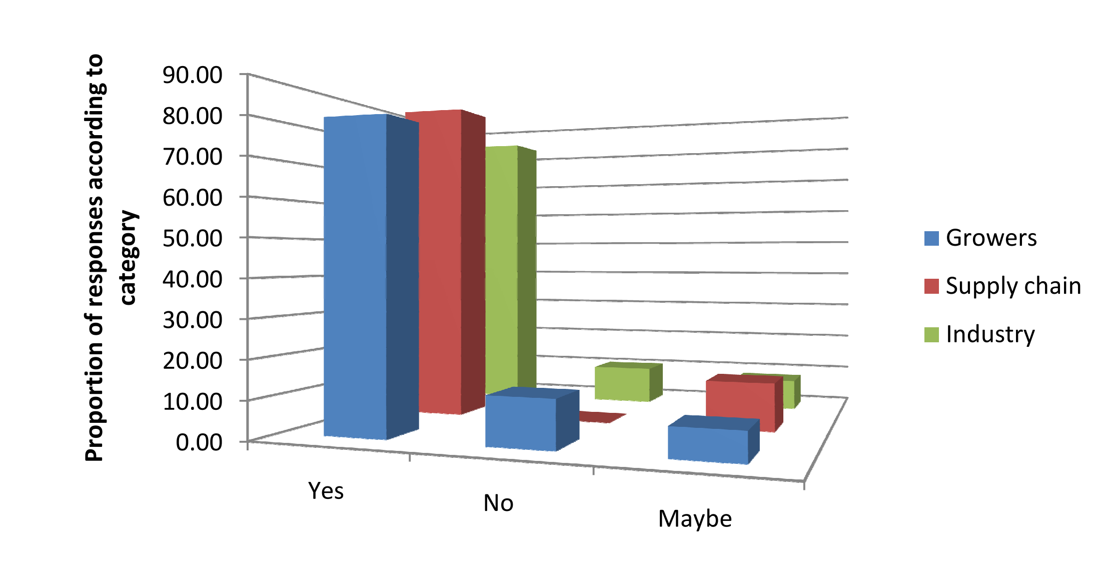


Figure 4-30 'Is the industry concerned with the changes in the pesticides directive?' Responses were separated for growers alone and supply chain alone, and the whole industry together.

Supply chain actors were slightly more concerned than growers, with 87% of respondents saying that the changes in the Directive would affect the industry. A supplier of chemicals to the Scottish strawberry industry said:

"A lot of good products have gone. They'll be in huge trouble. Will they have a business? The way the rain pattern is, if these go, we're doomed. In down south [here referring to England] it's probably different and they probably could survive, but Scottish strawberries can't survive. The only way to survive would be to use products off label. It might work, but it's his own risk. They've got nothing else. It's a concern for us, but it's a huge concern for them." SS5

An agronomist working with the industry even said:

"At the moment many growers are not concerned. They think they'll find something else. ..... And we are starting to see some resistances in the UK of certain pests to some chemicals. And as soon as you remove one product you start getting into issues. It is a problem." SS3

Notwithstanding the potential threat of the change in the Pesticides Directive, the industry is still positive that it would survive these changes (Figure 4-31). Just over three-quarters (78%) of all those interviewed were positive that the sector will survive, with growers being slightly more positive at 81%. Very few of the respondents were concerned that the sector might not survive.

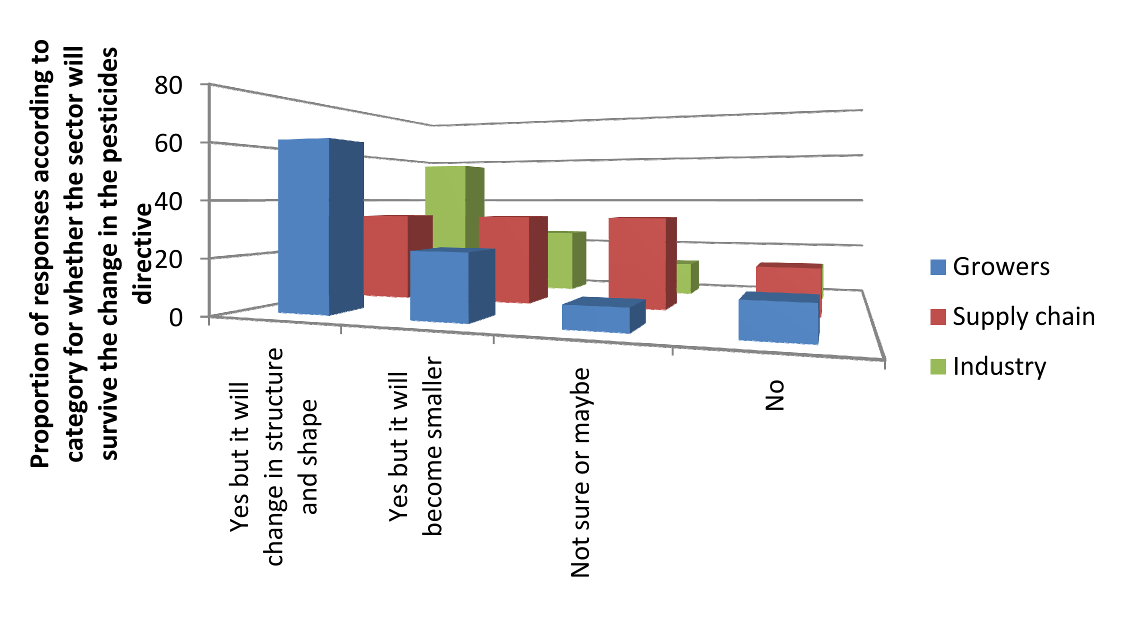


Figure 4-31 Vertical bar chart showing the responses of the whole industry, together with the growers alone and supply chain alone

Some suppliers of tabletops or specialist products such as polythene films that reduce wavelengths that affect pests even saw it as an opportunity.

"For ... [our] polytunnel business it is beneficial, because more growers will use polytunnels. Once you go under tunnels, routine sprays can be eliminated. Under a tunnel it is the powdery mildew which is more of a challenge. But our clients see that polytunnels is a good way to reduce the use of pesticides. Our clients, there's a general feeling that they can reduce up to a third of the chemicals if they use polytunnels." OS1

With regards to impacts, Growers' responses were slightly different to those of the rest of the supply chain. Whilst both agreed that the sector will have to change to adapt itself, the growers also suggested that the price will have to increase; the rest of the supply chain pointed out that a reduction in choice of available pesticides might also lead to an increase in disease resistance to pesticides (Figure 4-32).

When the interviewees were asked how the sector could adapt to survive these changes, the two main responses were either to switch to substrate production or to increase the use of biological control.

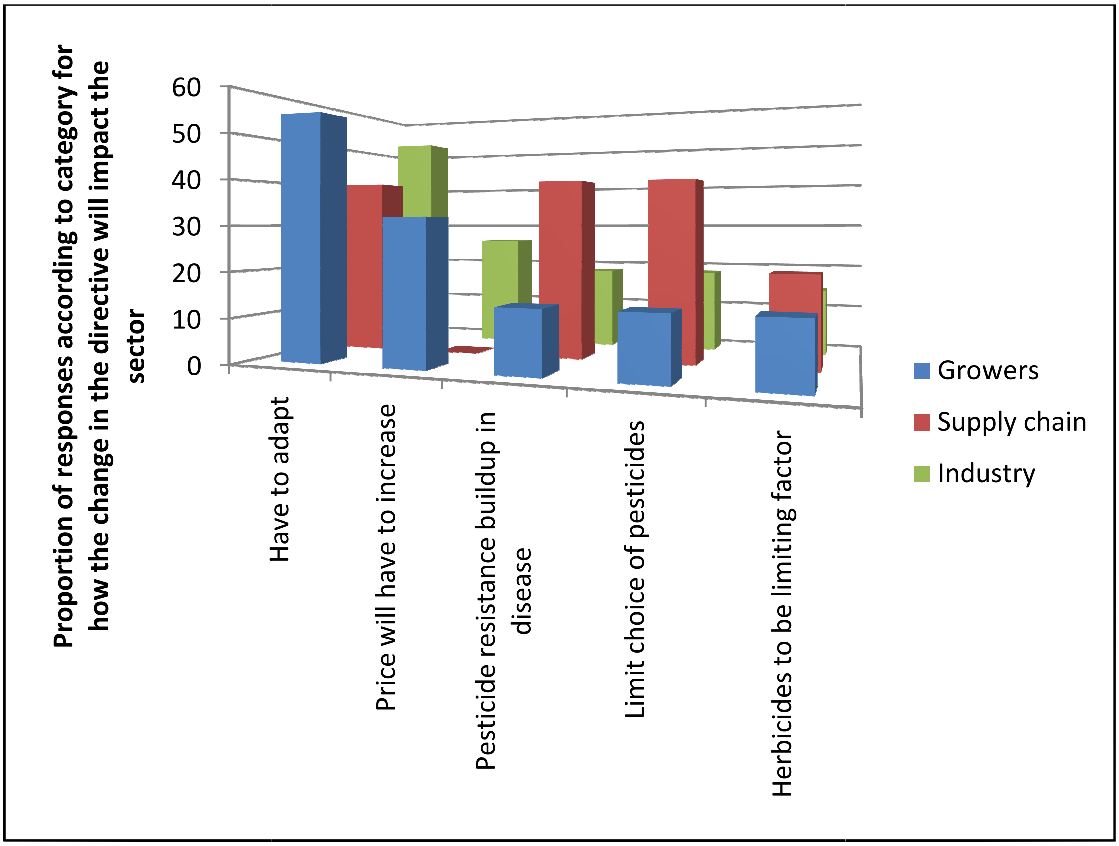


Figure 4-32 Vertical bar chart showing the responses of the whole industry, together with the growers alone and supply chain alone.

4.4.2 Discussion - Plant disease and its influence on the sector

Plant disease has been seen as an important driver of change in the strawberry sector in the past (Ellis, 1970, Rendell, 1973, Beech and Simpson, 1989, Lieten *et al.*, 2004, Lieten, 2006). Up until the 1950s, yields were highly influenced by weather and any growth within a business was limited by its susceptibility to disease. Though many new production methods have now been introduced to reduce loss of crop to plant disease, through this study, plant disease was seen as being the fourth major risk to the strawberry sector, with a third of all growers seeing it as a threat (Figure 4-33). When taking into consideration the potential loss of chemicals due to the overhaul of the EU Pesticides Directive, this threat came second only to labour, with around 70% of the industry seeing it as a threat. Notwithstanding this, the impacts, costs and susceptibility to disease can vary depending on production method, type of farm and cultivars used.

4.4.2.1. Disease frequency and severity

Whilst a bigger proportion of small farm enterprises saw disease as a threat, few of them ranked it as a high risk to their farm. Strawberries usually make up less than a quarter of their turnover on average and, since they demand higher prices and thus enjoy a better profit margin, they are more capable of absorbing any loss of crop from disease. Two thirds of large farm enterprises, on the other hand, saw plant disease as a major risk to their farms since a larger portion of their business is dependent on strawberries, and they also enjoy very tight profit margins, thus making any potential loss from disease a blow to the business. This explains why a greater proportion of large farm enterprises use agronomists. Moreover, whilst small farm enterprises use agronomists too, their visits to the farm tend to be occasional, in contrast to weekly or fortnightly visits to the large farm enterprises.

The production system also affected susceptibility to disease. Strawberries grown in the ground were seen as being more susceptible to disease than plants grown in soil-less growing media (substrate). This was because using substrate eliminates potential soil borne diseases such as *Verticillium* and red core, and also allows the growers to use less pesticides (Lieten *et al.*, 2004). When it does happen, however, the diseased plants are usually isolated to a number of bags, which can be thrown away, thus solving the problem since the disease has most likely come in with the plant from the nursery.

B. cinerea and powdery mildew were again found to be the most common plant diseases on a strawberry farm. In the latest pesticides usage survey for strawberries carried out in 2006, Powdery mildew and *B. cinerea* accounted for over 95% of the specified reasons for use of fungicides (Garthwaite *et al.*, 2006). The other common diseases are *Phytophthora cactorum*, Red core and Verticillium wilt. When analysing the disease incidence by farm type, it was seen that strawberry black spot was present almost exclusively in small farm enterprises, particularly in strawberries that were out in the open field. This made them susceptible to rain splash, which is the main means of spread of the disease. In fact, whilst being common in the 1980-90s, it is now virtually absent from the strawberry sector because of the use of protection, which practically eliminates it. This trend was also observed by ADAS inspectors in their 2008 disease incidence report where they mentioned that black spot was present mainly in outdoor crop (Lole *et al.*, 2009).

B. cinerea was most common in ground cultivation, with a lower incidence in substrate production. The latter method of production helped decrease *B. cinerea* since raising the plants above the ground meant that the level of humidity around the plants in the cooler part of the season (when strawberry plants are susceptible to *B. cinerea*) was less since it was easier to control the water content in the substrate. On the other hand, in ground production, even under protection, *B. cinerea* was seen to increase after heavy rains and water logging. In the 2008 ADAS report, inspectors suggest that *B. cinerea* was “generally not a problem inside Spanish tunnels apart from the leg rows, where leaks tend to occur and air movement is more restricted” (pg88) (Lole *et al.*, 2009).

B. cinerea was also seen as the disease causing the greatest economic loss. The impact in small farm enterprises was particularly severe, being twice that in large farm enterprises. It again caused the greatest economic impact on ground cultivation, particularly in the open field since its epidemiology favours infection in those conditions. This is corroborated by a study that compared the incidence of *B. cinerea* in field and protected systems, where *B. cinerea* was consistently found to be more widespread in the former (Xiao *et al.*, 2001). The economic impact of *B. cinerea* in this research was found to be from loss of fruit and decreased sales, shortening of the post-harvest lifespan of the fruit, and also from the sheer cost of fungicides used to control it.

Powdery mildew was most common in substrate production and was seen as being the single most common disease for that production method. The reason is that powdery mildew is known to be more severe under polytunnels due to the high humidity levels reached under those conditions, which are ideal for the spread of the disease (Xiao *et al.*, 2001, Freeman and Gnayem, 2004). In terms of economic impact, it was perceived as being only the third worst disease, behind *B. cinerea* and Verticillium, because it is cheaper to control than *B. cinerea* through ample ventilation during the warmer months. It was also seen to be a bigger problem for large farm enterprises, especially for those using substrate production. In fact, none of the farms using solely ground cultivation suggested it as being an economic problem to their farm, most probably because, as Xiao *et al.* explained, the plants are at slightly cooler temperatures at ground level and powdery mildew is not as severe in those conditions (2001).

Verticillium wilt was seen as the disease causing the second most economic impact on a strawberry farm. This was mostly due to the abandonment of fields having *Verticillium* because of high inoculum levels. In fact, one of the first tests done by the agronomist in the beginning of the year before the new plants are put in the ground is the wilt test, to determine if wilt is found in the soil. If it is, that field would have to be abandoned for a number of years and another would have to be found. This is a big problem for growers having a limited amount of land and those having grown strawberries for a long time because disease incidence in *Verticillium* is proportional to the amount of inoculum found in the soil (Harris and Yang, 1996), thus successive cropping increases any risk of disease. Whilst being a problem for the whole sector, it is a particularly bad problem in certain regions of the UK (Raffle and O’Neill, 2006). This was found to be one of the main reasons why growers rent new land, so that they can continue growing strawberries in the ground in a rotation. Those that do not have new land available often have to move or raise the strawberries off the ground onto tabletops. The process has been hastened in the last ten years with the removal of methyl bromide as a soil sterilant, since the disease cannot be eliminated as effectively from the ground through the permitted chemical means (Goicoechea, 2009).

4.4.2.2. Disease management

The epidemiology of plant disease is such that particular conditions are needed for infection and spread to occur. These vary from disease to disease, but are highly dependent on a number of factors that are influenced by weather, such as temperature, humidity and the presence or absence of free water in the air (Maas, 1998, De Wolf and Isard, 2007). Thus it was to no surprise that almost 90% of the growers suggested weather as being the most important factor causing disease spread in strawberries. This was the reason why so many growers went into using polytunnels in the last 15 years, to be able to reduce their vulnerability to the weather by eliminating the effect of direct rainfall on the crop (Freeman and Gnayem, 2004). When this is not enough, they rely on other means of reducing the spread of disease, such as using resistant varieties and chemical means of control. In fact, the use of chemicals such as fungicides and having a good spray programme were seen as being vital to the control of disease. The latter in particular was seen by small farm enterprises as their best option for avoiding disease, in the absence of protection from the prevailing weather.

This dependence on chemical means to control plant disease has made the sector reliant on the availability of effective fungicides. A large proportion of the industry, and especially the wider supply chain, are concerned about changes in the availability of plant protection products in the future. Nevertheless, the scale of the changes is still not clear. Whilst more chemicals find their way off the permissible list, some growers remain optimistic that other chemicals will be developed. In reality, the suppliers of chemicals are even more pessimistic. They see the strawberry sector as being a small market for the big manufacturers of pesticides. According to their testimonies, all the research and development into new chemicals and pesticides is being targeted towards the main crops such as cereals and no new research is being carried out on soft fruit by the big chemical companies.

Notwithstanding the loss of some plant protection products in the future, this study has shown that the industry is most likely to adapt itself to this threat. This will most probably involve a change in the size of the industry and the way strawberry growers grow their crop. Whilst many businesses will find it hard to survive, some are expected to benefit from the reduced competition and deficit of product on the market. Prices will most probably rise, making the survivors benefit from the reduction in the size of the industry. Those farms most reliant on the use of chemicals will be more vulnerable, such as small farm enterprises growing crops in the open field. There will be increased use of technology and cover, whilst more of the crop will be raised off the ground. Crop yield might decrease and cultivation will become more intensive with the grower having to give more attention to detail to reduce loss from disease.

Nevertheless, the sector will survive as long as there are clients willing to pay more for British strawberries. Some growers even see their business benefiting in terms of competition against the European market. The industry is considered to be so developed in the UK, and so much technology is used in production, that some of the leading players in the sector believe that UK growers are well placed to take advantage of reduced competition from other countries who do not use the same amount of technology and might not have the yields and product to compete with the British market.

4.5. CHALLENGES FACING THE UK STRAWBERRY SECTOR

In this section, the challenges faced nowadays by the strawberry sector will be analysed. These data emerged firstly from the postal questionnaire, whereby the growers where asked a number of questions regarding threats and opportunities within the sector. After analysis of the data, two themes were analysed in further depth through the semi-structured interviews: the impact of labour and regional differences within the sector.

In the following results section, the overall threats and opportunities are first analysed. This is then followed by in depth analyses of the impact of labour on the strawberry sector, and how regional differences affect the strawberry sector in Scotland and in Kent.

4.5.1 Results

The strawberry sector, as seen from within the industry, is being faced by a number of threats. When growers were asked to list and rank up to four threats they face nowadays, over thirty threats were identified. When grouped into loosely associated categories, there were 16 different threats (Figure 4-33). The biggest threat of all was the cost and supply of labour, noted by just over 80% of respondents. It also obtained the highest number of highest ranks, by around 32% of the sector. The second biggest threat was the loss of chemicals due to changes in the Pesticides Directive (70% of respondents). Nevertheless, few of the growers ranked it as the most important threat.

Other important threats came from imports and pest and disease issues. Weather was the 8th most important risk and climate change came 11th with around 12% of the respondents considering it as a threat.

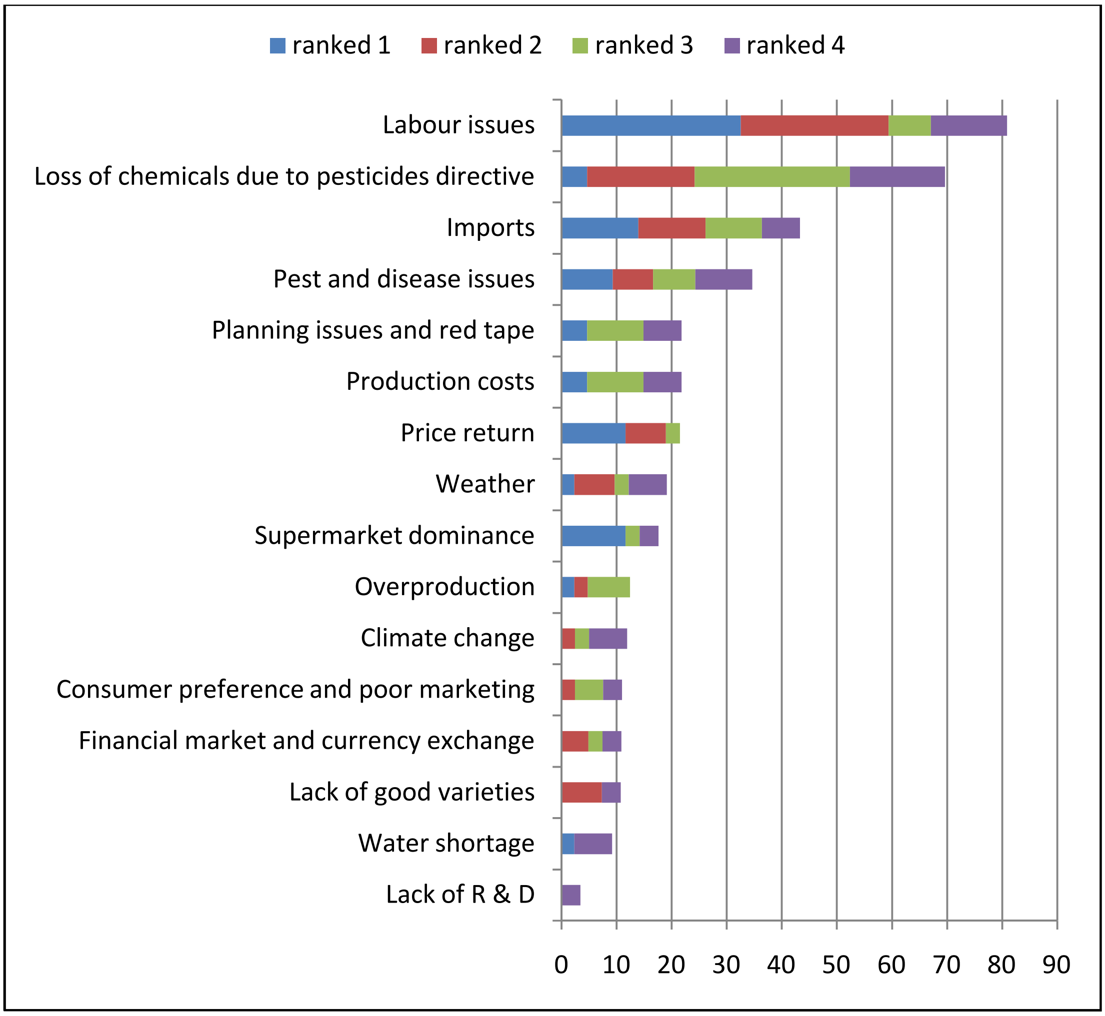


Figure 4-33 Stacked bar chart showing different threats faced by the industry. The growers were asked to rank the threats from 1 to 4 with 1 being the most important. Data collected from questionnaire.

In terms of the size of the strawberry enterprise, imports were seen as a threat mainly by small farms, together with pest and disease issues and the weather. On the other hand, labour issues were more of a problem for large farm enterprises. The latter also had a problem with prices, planning issues and red tape.

Notwithstanding the number of threats present, the sector also saw opportunities to advance their business. A total of 19 opportunities were listed by growers (Figure 4-34), with an increase in regional and local sales being the most important. This was also seen as being the most important opportunity by the biggest number of growers. Development of disease resistance was seen as the second most important opportunity, with the UK's "5 a day" healthy food strategy and the popularity of the "British strawberry" coming in third and fourth places. A few of the threats found in

Figure 4-33 were also described as opportunities by some growers. Examples include climate change, the weather and the availability of good varieties.

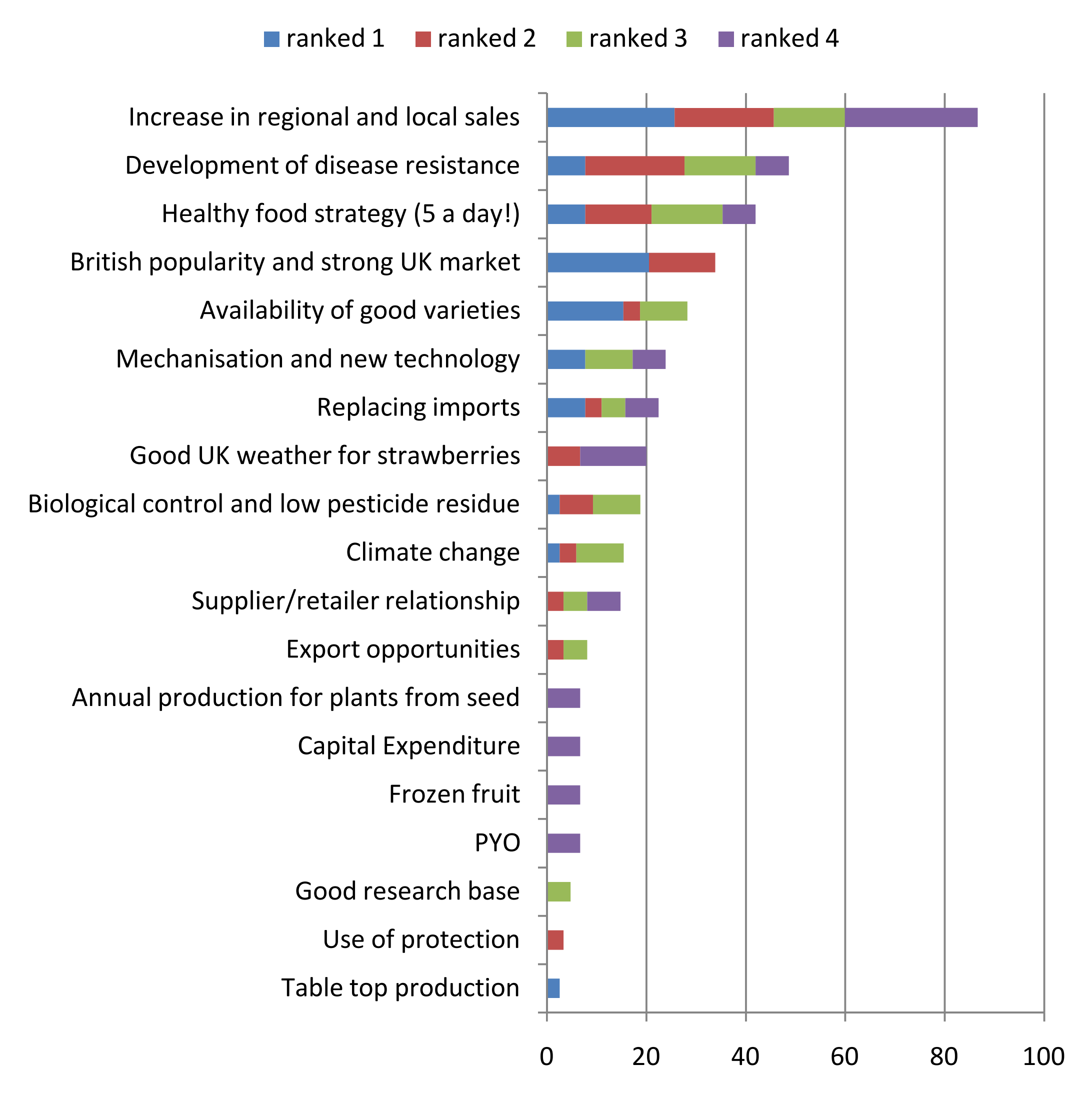


Figure 4-34 Stacked bar chart showing different opportunities faced by the industry. The growers were asked to rank the opportunities from 1 to 4 with 1 being the most important. Data collected from questionnaire.

On dividing the responses by farm size category, the majority of growers wanting to increase their local and regional sales are those with small farm enterprises. Large farm enterprises were more interested in improving production techniques and increasing yield by introducing mechanisation and new technology, using more disease resistant varieties, and being able to grow more crops using biological and other methods that achieve nil pesticide residues. These growers were also interested in replacing imports and capitalising on the UK market and healthy food strategies to achieve more sales.

4.5.1.1. Specific threats: labour

Labour issues were discussed in depth during the case study interviews as a major risk to the future of the strawberry industry. Casual labour in the strawberry industry now accounted for 90% of all labour. This workforce can live, work, eat and sleep on the farm in caravans provided by growers. The growing season has become so long that farms need to employ workers for longer periods of time. The sector has also become so intensive that strawberries are picked every day throughout the picking season. Picking often starts early in the morning and continues throughout the day into the evening, except in the warmer hours of the day. This means that the workforce needs to be flexible enough to be close to the farm and easily available. As one grower in Kent said:

"Local just don't want to do it. They don't see it as a proper job. Sometimes they turn up and sometimes they don't. It's a temporary job so they won't come out of unemployment to do a temporary job. And the UK students they don't get out of school before July, and we have a full workforce by then so we don't have a job for them." KG1

Secondly, both the supply and/or cost of labour emerged as important threats to different types of growers.

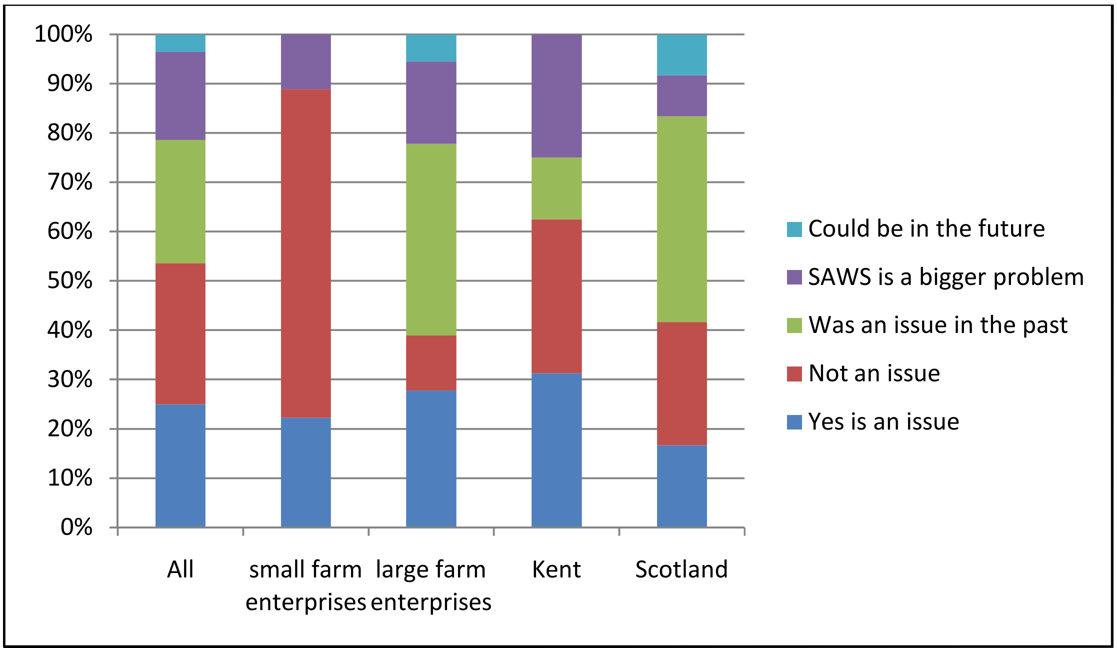


Figure 4-35 100% stacked chart showing the ways in which labour supply can be an issue for the strawberry industry

The supply of labour is only a major issue when market forces and legislation regulating the employment of foreign workers conspire to dissuade non-EU workers from coming to the UK to work on strawberry farms (Figure 4-35). Before the recession hit in 2009, labour supply had become a serious problem due to the reluctance of students from the new member states such as Poland and the Baltic states to work in the UK. This was due firstly to the fall in the value of the pound and secondly to the improved wage levels in Eastern Europe, making strawberry picking in the UK less attractive. To add to this, the Seasonal Agricultural Workers Scheme (SAWS) had reduced the quota of non-EU agricultural workers that could come to the UK to seek temporary employment in the horticultural industry. A Scottish grower that was involved in the NFU described what happened:

"Last year (2008) we struggled to get enough workers. I did some work with the NFU to get the government to give us more work cards [for the Bulgarians and Rumanians]. They originally restricted it to 15,000. They stopped the Russian and Ukrainian workers too. And we asked them to increase it by 5,000. And then in 2009 with the recession taking a knock in Eastern Europe it meant that we were able to source more work labour from Slovakia and Poland and the Baltic states, because suddenly there wasn't that much work there." SG10

This shift in focus of the SAWS, from Russian and Ukranian workers to Bulgarian and Romanian, was encountered on many farms and was perceived as causing a drop in the quality of workers available for the summer season.

"In the old agricultural workers scheme the people coming working all really wanted to work and the exchange rate was good and they were motivated, but it's different now. ... We had some really good Ukrainians, and everyone went on really well. And those economies especially the ones that have joined Europe are quite different. Now that they come, it's not much different for them, and with the rubbish exchange rate the wage isn't that attractive anymore." KG16

Whereas labour supply is an issue for around 25% of the sector, labour costs are an issue for over 50% of the sector (Figure 4-36). A particularly clear distinction between small and large farm enterprises was found, with 40% of small farms stating that it was not a threat for their business, compared to 5% of large farms. Some farms see it as being such a big problem that they have decided not to increase the size of their business:

"It's a limiting factor with respect to not attracting new growers because the costs are so high, and certainly limits growth, which could be a good thing. You could become more efficient but there's only so many ways that you can increase your efficiency." SG8

One grower, who is also a Director of a Producer Organisation, added:

"The biggest problem potentially for strawberries is the price in relation to the production costs, and the biggest production costs are labour. The difference between the price and the cost of labour is getting smaller every single year. Price hasn't changed in twenty years but the labour costs have gone up fourfold. And don't forget the agricultural wages minimum wage is much harder than the [national] minimum wage. Much harder." KG3

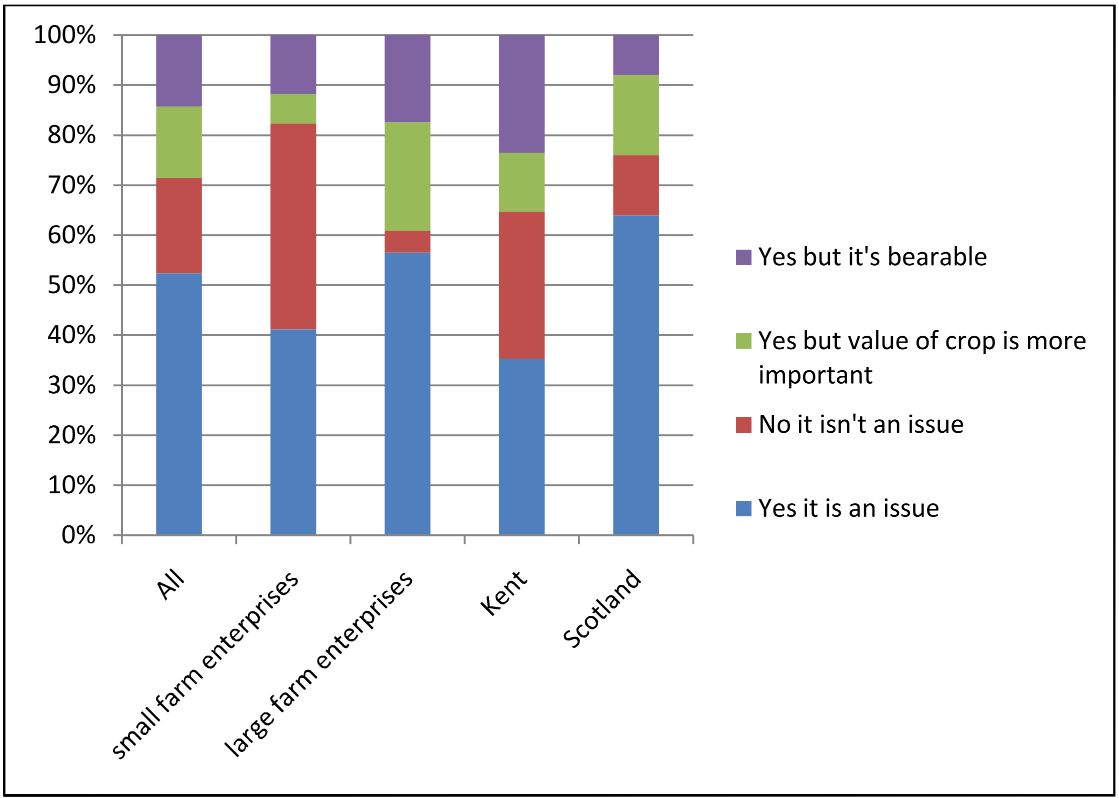


Figure 4-36 100% stacked chart showing in what ways labour cost can be an issue for the industry.

Variation in the labour threat was also observed between Kent and Scotland. Scottish farms were seen to have a greater problem with labour costs, with over 60% of them considering it to be a big threat to their business compared to 35% in Kent (Figure 4-36).

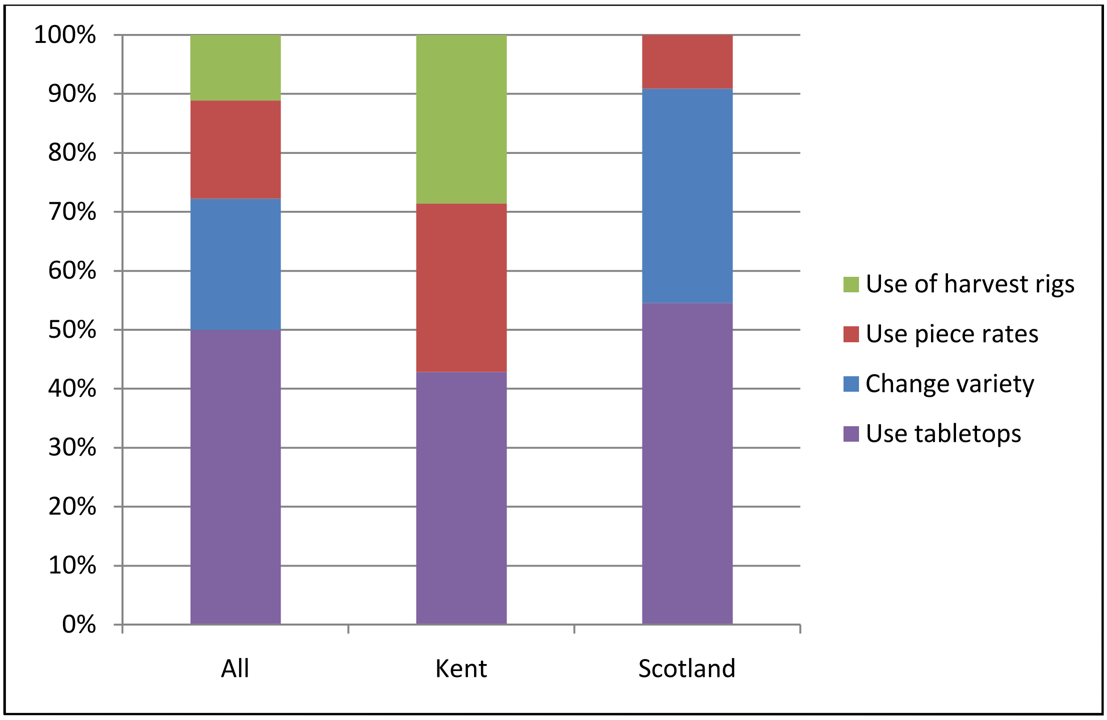


Figure 4-37 Stacked chart showing the methods used within the strawberry sector to lower the labour costs.

The threat from labour costs is quickly becoming one of the major driving forces behind change in the industry. To adapt, a good proportion of growers have been going into using tabletops, substituting ground production with substrate production. 50% of the interview respondents suggested using tabletops as an adaptive tool in response to rising labour costs (Figure 4-37). One grower, who is also the director of another Producer Organisation, said:

"All our strawberries are on tabletops. So you're picking standing up. Picking costs are cheaper. And that's why we only grow 90 acres. We'd probably have 150 acres on the floor. Was paying £3/hr when I started and now we're paying £5.80/hr. In 1996 I was averaging £3.40/kg, and now we're lucky to get £3/kg. Then we were growing 70-80 tonnes, now we're growing 1400 tonnes." KG19

Some also buy tabletops to attract workers in order to solve the labour supply issue. As one big player in the Scottish Industry said:

"Labour is a big issue for tabletops. Who wants to pick a field when it's on the ground when you can do it standing up? It makes it more attractive for workers too.

This year wasn't such a problem for labour. But it will come back again. Shortage of labour. If you could have all your production on tabletops and you could reduce a third of your labour, it means less management, less problems to accommodate them on the farm. It would be considerably cheaper to pick the crop." SS3

The next most popular method of lowering labour costs is changing to a variety that is easier to pick and enables the fruit to mature all at the same time. Another technological method used to lower labour costs is the harvesting rig, which was recommended by almost 30% of the sector in Kent. One grower that uses harvest rigs added:

"we put 40 on rigs and about 80 people picking traditionally by hand. But we put the slowest people on rigs. And that would lift their productivity to a wee bit above the quick pickers. You could almost say that we doubled the speed of the pickers by targeting the slower pickers. It wouldn't double the speed of the fast pickers. And this year we were saving probably 10p a kilo on our picking cost which on a 1000 tonnes is quite a significant cost. The slow pickers absolutely love staying on the harvesting rig. It's a big issue if we take them off the rigs." KG1

4.5.1.1.1. Impact of labour on local communities

The employment of a large casual workforce on a farm was seen to bring some benefits to the economy of these rural areas. Whilst most of the casual workforce lived on the farms in caravans, some, particularly the longer-term workers who stay up to ten months in the UK, rent rooms in local towns. Many also buy bicycles to travel to local shops. The larger farms also provide transport (possibly rented coaches) to take workers to local supermarkets for shopping. Local taxis are often seen around the farms, and some of the workers may buy their own cars. In some remote areas, local shops and bus services seem to depend on the presence of the migrant workforce. As one grower in an area known for its concentration of large strawberry farms said:

"We're talking about well over a 1000-2000 east Europeans [here]. That's a lot of shopping. The amount of taxis that come to and from the farms. Because they haven't got cars. We've had taxi cabs come in with a wad of business cards and asked us, "please give these to your students". Even offering all sorts of cash deals if I pushed

them through. You wouldn't get all this if they were English students, because they'd all have their own car." KG3

Another grower in Scotland said:

"They get electronic goods cheaper from here so they buy things from here and take it back. It would be interesting to see a weekly spend at the supermarket by a picker. They do go and buy laptops and ipods." SG10

This was encountered on many of the farms that were interviewed, especially the large farm enterprises. Electronic goods may be cheaper in the UK than in their country of origin and many of these workers prefer to take their money back as goods rather than as currency, especially when the Euro is strong in relation to the pound. Some even used part of the money to travel around the country and visit other regions. On one particular farm that employs around 500 foreign workers, the buying of local goods by their foreign workforce reached such proportions that it became a problem for the farm.

"Our biggest problem here is that everyone comes over here works for a few months, and buys a car. Probably 100 cars were bought this year. We're not set up for parking hundreds of cars around the farm, and you can't let them park outside because that will upset the village. I ended up choosing a field, and everyone would park there. And good cars too. Another thing a lot of people buy are computers. Huge amount of computers they've bought. Which is why I put in a campus-wide, zerus array wireless network into the camp, so it can take 400 users. Because everyone buys laptops. I've had an Internet café here for a few years but they don't need it anymore here. The big buys on the electronic side are laptops, DVD players, flat screen TVs, and clothes." KG14

4.5.1.2. Local and regional challenges

In order to understand the implications of local and regional challenges, and their impacts on the business concerned, one needs first to understand why a business chooses to locate itself in a particular region. The reasons are sometimes strategic, which means that the business specifically chose that location for the opportunities found within that geographic area, be it a town, region or country. Some business owners have always lived there, and so have chosen the type of business rather than the location, depending on the opportunities made available in that region.

Through the case study interviews, it became apparent that, in some form or another, 95% of the growers are located within that geographic region for reasons that have nothing to do with strawberry production (Figure 4-38). Around 75% of the farms inherited either the farm or the tenancy, whilst another 20% bought the land because it was conveniently available. Less than 5% moved to a new location with their strawberry business for reasons that were due mainly to improving production and yield, one of which was in Kent and another in Scotland. The grower in Kent elaborated on his reasons for the move:

"Moved here from western Kent [13 years ago] because the soil is lighter and better for strawberries. Not too much clay. In the past red core was the problem on the old site. We had trouble with establishing good root systems so yields were poor. And then they doubled when we came here. We've doubled them on the move and then doubled them again since we're here. Average yield here is about 27-30 tonnes/hectare, but we've had 50 tonnes/hectare at best." KG1

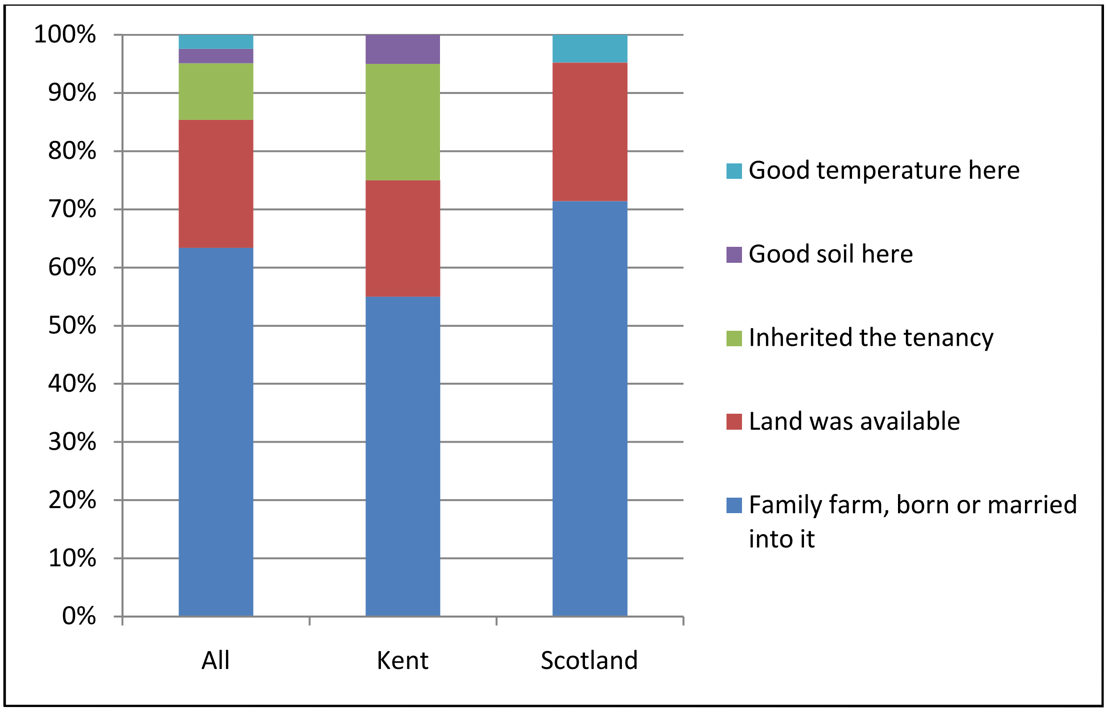


Figure 4-38 100% stacked chart showing why the farm business is located in that particular area.

Whilst local or regional challenges can often offer opportunities to a business, they can sometimes create great pressures that may even force a business to move, change crop, or even close down completely. The interviews identified a number of geographically-specific challenges that put pressure on the strawberry businesses within these regions (Figure 4-39). Planning permission was seen to be by far the biggest problem in Kent with 25% of the growers mentioning it as a challenge, as compared to less than 5% in Scotland. As one grower in this area described:

"The British planning system is appalling. It doesn't really help you. There's too much noise about polytunnels being unsightly. It all started this year. No one ever said anything about it before. And it's because a lot of wealthy people have moved into the area. And someone said something at a drinks party, and bang. It all kicked off. But we've been growing polytunnels for 20 years. It's always people who come in who make problems. There's a lot more offensive things out there [than polytunnels]. And once they're gone you can't even tell they've been there." KG14

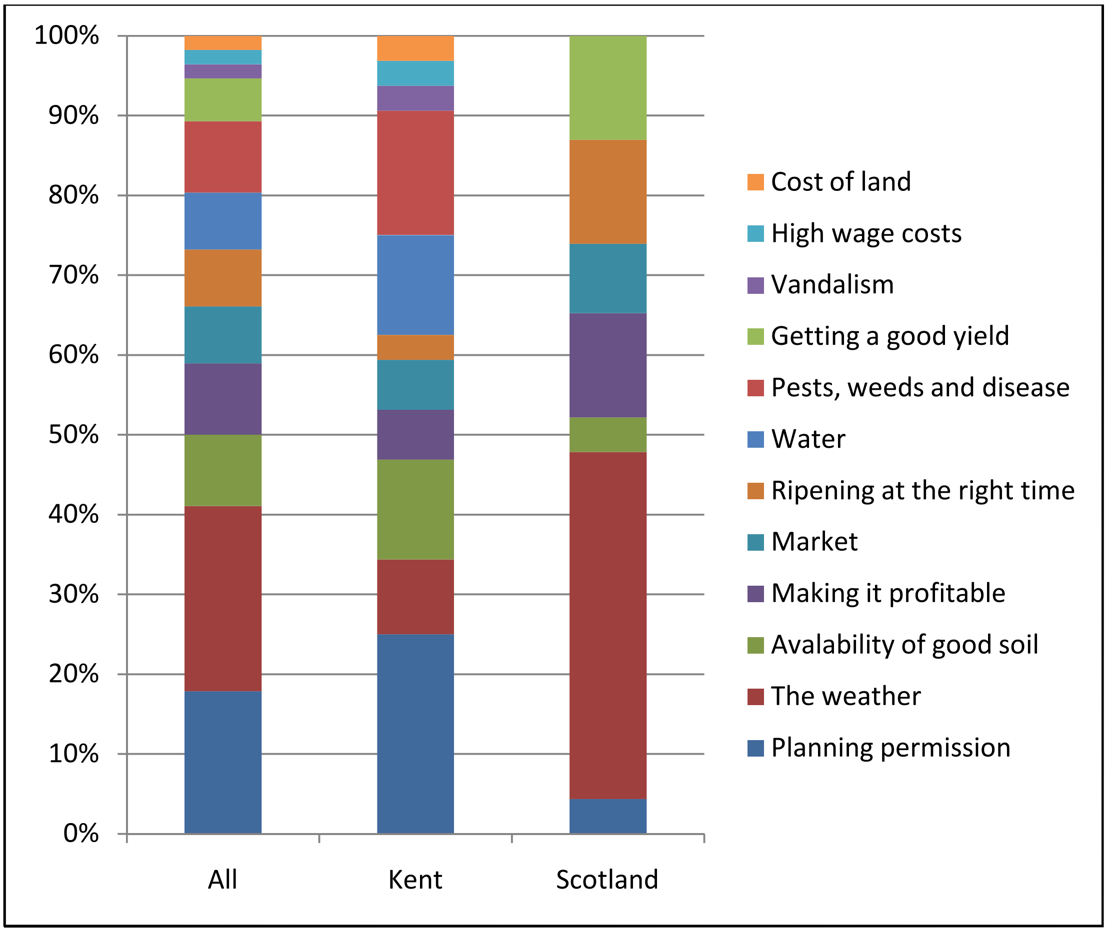


Figure 4-39 100% stacked chart showing the challenges faced by the strawberry industry in Kent and Scotland.

This is a particularly bad problem for growers in the area around Maidstone, forcing some businesses to rent land elsewhere in other counties further away from big cities. As a retailer based in Kent said:

"Growers in this part of the world are having to seek planning permission to build their polytunnels and that is proving to be an extremely costly and painful exercise, although necessary. In the Maidstone area and south of London it is worse because a lot of rich commuters come and live in these areas and they don't want to see polytunnels in the countryside." KS1

The availability of good soil (disease free) is another important challenge in Kent, being mentioned by 30% of the respondents compared to less than 5% in Scotland. As one grower said:

"Doing a rotation here is quite difficult because of Verticilium wilt because we're limited on land and there's not much where we can move. I guess if we can't rotate our strawberries anymore we'll just have to pack up and move somewhere else. If the other generations will want to carry on, that's what they'll have to do. As we're tenants we can move." KG15

This was found to be one of the main reasons that growers rent new land, so that they can continue growing strawberries in the ground in a rotation. Those that do not have new land available often have to move or else raise the strawberries off the ground onto tabletops. Nevertheless, many growers prefer to grow strawberries in the ground, as long as one has enough land to rotate. The costs of tabletops are inhibitive to many who do not have financial reserves to fall on. As one grower, who moved to a new location in the last 20 years to find new clean land, said when asked which method he thinks is the most productive:

"In the soil. I think we can get the same yields as tabletops. I think the capital costs of tabletops are very high. And personally I think the only real saving on tabletops is labour. I think tabletops work for farms that have inherent problems in the soil. So whether it's the wrong soil type or not. Some farms have been growing strawberries for a very long time and the soil is quite tired of growing strawberries. Long term I think we'll all be on tabletops, because we're losing chemicals at a rate that I think we can't grow in the soil for very much longer." KG1

Water availability was another notable challenge that was mentioned by around 12% of growers in Kent as compared to none in Scotland. In Scotland, too much rain and not enough sunshine was a problem. The weather was by far the biggest challenge, with over 40% of the respondents in the region referring to it as being a problem, compared to less than 10% in Kent. Two other challenges that derive from the influence of the weather in Scotland were getting the crop to ripen at the right time and obtaining a good yield, with just over 25% of respondents in the area referring to it as being a problem, compared to less than 5% in Kent.

Finally, twice as many growers in Scotland found it challenging to make the business profitable. One particularly influential Scottish grower went on to describe the challenges faced by the strawberry industry in that region:

"Trying to stay viable. To make a profit. Employment law has changed. Scottish production is not early enough to gain the early season price premium that growers in the south of England can achieve. And we also don't have the modern, the newer varieties that would be nice to grow the everbearer varieties that are later in the season. The Scottish climate is not as favourable for those varieties, so we don't get the same yield. We just don't get the right yield. I question whether other growers in the area can get a favourable yield if I don't manage." SG12

In order to investigate further some of these issues, data obtained from the questionnaire and interview were analysed across the two regions to test for differences in yield, productivity and disease incidence.

4.5.1.2.1. Geographic differences in yield and productivity

Data for farms in Kent and Scotland were compared (Table 4-10). Although many differences were observed, few were statistically significant. Of those that were, Scottish growers tend to own a larger proportion of their land than growers in Kent and a greater proportion of their turnover came from strawberries. However, farms in Kent obtained better picking rates per worker than farms in Scotland. Differences in yield and overall farm size were not found to be significantly different.

Table 4-10 Differences in farm factors. A one-way t-test was performed to test whether one mean was larger than the other. Data for this table were irrespective of farm size.

Farm variable	Kent vs Scotland	P value	Degrees of freedom
Overall farm size (Ha)	133 196	0.118	39
Proportion of land owned by grower (%)	57.35 82.39	0.032	39
Proportion of turnover coming from strawberries (%)	40.0 56.0	0.042	38
Yield (Tonnes Ha^{-1})	25.08 21.55	0.138	30
Full time staff numbers on strawberries (people)	9.1 3.1	0.093	38
Casual worker numbers on strawberries (people)	88 120	0.208	38
Tonnes harvested per picker	6.266 3.762	0.007	29

The data for a number of categories were tested for differences between large farm enterprises in the two regions (Table 4-11). The yield was the same for farms in the two regions; however, some other variables were found to be different, even though not statistically significant.

*Table 4-11 Two-sample unpaired t-tests, testing for differences in five variables for **large farm enterprises** from the two regions. Data for small farm enterprises were not tested.*

Production system	Full time staff	Yield	Tonnes per picker	Proportion owned	Proportion turnover
Kent_mean (Median)	17.87 (5.7)	24.53 (23.75)	5.995 (6.266)	54.69 (73.46)	60.6 (60.0)
Scotland_mean (Median)	4.33 (3.75)	24.66 (22.08)	3.649 (3.417)	82.46 (100.0)	68.64 (65.5)
P value	0.059	0.970	< 0.001	0.058	0.188
T-test	y1 > y2	Two-way	Two-way	y1 < y2	y1 < y2
df	22	22	22	22	22

The only variable that was found to be statistically different was the picking rate or productivity of the workers in the two regions. Large farms in Kent had a higher picking rate than in Scotland by around 64%. When the median was taken into consideration, the picking rate in Kent was around 83% higher than that in Scotland.

4.5.1.2.2. Geographic differences in disease prevalence

The two most common diseases in Kent and Scotland were *B. cinerea* and powdery mildew (Figure 4-40). Whilst powdery mildew was equally common in around 90% of the farms in both regions, there were differences encountered in all the other diseases. *B. cinerea* was found to be a problem on every farm in Scotland, while fewer than 70% of the farms in Kent recorded it as being a problem. The same trend was followed for *P. cactorum* and red core, with these diseases being more common in Scotland. On the other hand, Verticillium wilt was a bigger problem in Kent with 50% of the farms recording it on their land, as compared to around 35% in Scotland.

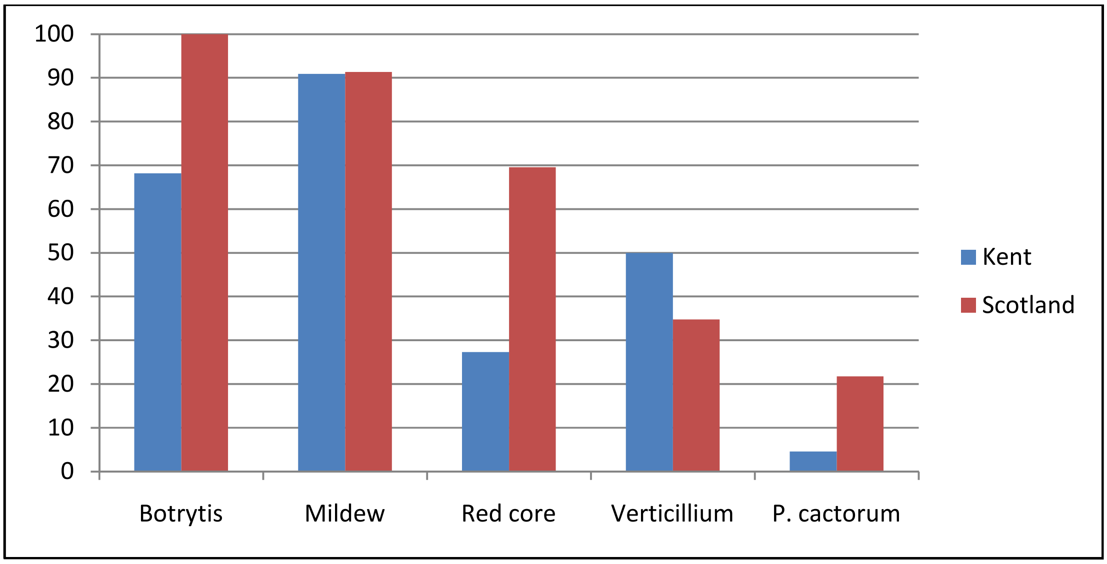


Figure 4-40 Vertical bar chart showing the proportion of growers in Kent and Scotland recording diseases as being common.

4.5.2 Discussion

Through this study, it has been seen that agricultural change in the strawberry sector has brought about a change in the way strawberry crops are grown and farms run. This has inevitably brought about the existence of new threats, and the downscaling of others, such as plant disease. Whilst still being considered as the fourth major threat (thanks to the availability of plant protection products: see section 4.4.2.2), issues related to labour have become the biggest threat to the sector. This has in itself influenced the sector in a number of ways, partly by affecting individual businesses but also by acting as a driver for change.

On the other hand, regional challenges, unlike threats faced nationally, can affect the industry locally and might even be endemic to particular regions. These factors may create differentiation in a sector which could be geography specific, but could also lead to the industry thriving in one region and going into decline in others.

4.5.2.1. Labour and the strawberry sector

The use of labour in agriculture has changed drastically during the last 100 years. Whilst in 1956 casual labour (non-permanent labour) accounted for some 13% of all family and hired labour on a farm, by 1984 this proportion had grown to about 32% (Ball, 1987). The strawberry sector is particularly dependent on casual labour, due to it being a highly labour intensive crop and, as farms gradually became larger, so did the workforce employed on the farms.

Over the last 20 years, the agricultural minimum wage has almost doubled, while the retail cost of strawberries has remained the same. The increase in labour costs was due mainly to the setting up of minimum hourly rates governed by the Agricultural Wages Board (AWB) (Errington and Gasson, 1996, Rogaly, 2008). Moreover, the tragedy involving the deaths of foreign workers at Morecambe Bay in 2004 gave the impetus to the Private Members' Bill to create a new licensing regime, which gave rise to the Gangmaster Licensing Authority (GLA) that came into force in September 2006 (Rogaly, 2008). The GLA is a government agency set up to protect workers from exploitation in agriculture, horticulture, shellfish gathering and food processing and packaging. The introduction of the GLA has resulted in rigorous inspections of farms to ensure the rights of the casual labour force, and farms that are not compliant have been taken to court. This has made labour a contentious issue in the strawberry sector that has often brought it into the headlines. In 2009, a grower was prosecuted for violating the Gangmaster (Licensing) regulations and for exploiting his workers and keeping them in appalling conditions (BBC News, 2010a). Other large farms have had problems with strikes, as happened in 2006 on one of the largest farms in the UK, when 500 workers walked off the farm in protest against exploitation (Farmers Guardian, 15 December 2006). This has in turn affected the labour supply to certain farms, such that they go to great extents to keep their staff happy and attract them back the following year. Nevertheless, the sector cannot survive without labour and no effective automated picking systems exist in the UK. Farmers use mechanisms to incentivise pickers such as piece rates to maximize their profits. In fact, the use of piece rates, together with the corporate retailers' requirements for volume, 'quality' and low margins (for growers), has lead to an intensification of labour, as farms try and get more and more tonnes out of their workforce, thus reducing their relative picking costs (Frances *et al.*, 2005, Rogaly, 2008).

The sector has grown to become heavily dependent on this foreign source of labour. As Rogaly (2008) explained in a study on the intensification of labour in horticulture, the preference for migrant workers "was much stronger in agriculture", whilst the same employers saw migrant workers as being 'crucial' to their businesses. Moreover, agricultural employers were the most hostile to the phasing-out of temporary migration schemes under the British government's new points-based system for the Seasonal Agricultural Workers scheme.

Thus, since the need for labour has become directly proportional to the growth of the strawberry sector, the sector's success over the last 15 years would not have been possible but for the availability of casual labour. Nevertheless, while wage costs have continued rising, the price of strawberries has remained the same, such that labour is now the biggest expense on a farm. Farms tend to deal with larger and larger workforces, with 500 workers not being an uncommon sight on a strawberry farm. This has become one of the biggest driving forces behind change in the sector, for a number of reasons.

Firstly, there is the change in farm size. Whilst large farms spend an average 45% of their costs on labour, employ 170 casual labourers and 10 full time staff on average, small farm enterprises spend around 30%, employing on average only 5-6 casual staff and on average less than one full time worker on strawberries. This makes small farms less susceptible to the problems usually encountered with labour. Moreover, as the labour force increases, farms are obliged to employ managers to oversee the casual workforce and further administrative staff to manage the payrolls. These are usually employed on a full time basis, adding extra costs to the business. This expansion of the workforce has often acted as a disincentive for growth by many of these small farm enterprises since they prefer to avoid having to deal with a large workforce.

Secondly, there is the change in the overall number of growers. Farms struggling with low profit margins and debts find it increasingly hard to deal with increasing labour costs. Consistent debts could lead to a farm business abandoning the sector, or closing down completely. Wealthier, more productive farms with better yields can absorb labour costs more efficiently, and even have economic sources available to fund innovative techniques that help improve yields and lower costs. They would be able to take over business from farms that have abandoned the sector and, in doing so, become larger. Thus labour could act as a driving force that will change the size of the sector by having fewer but larger farms.

Thirdly, there is the change in the use of technology within the industry. As farms try to adapt to the higher labour costs, new technological advances have been introduced to lower them. The introduction of tabletops is one such technological advancement. By having the strawberries at waist level, pickers do not need to crouch, thus they can work faster, get tired less, and this working environment makes it more attractive to prospective workers (Lieten *et al.*, 2004). Costs have been said to decrease while yields were seen to be significantly higher than those obtained in ground production. This has been the incentive for a number of large farm enterprises to introduce these systems. Thus unless other automated systems are introduced, labour could continue fuelling technological change in farms through the introduction of more tabletops and raising the crop off the ground. This in turn would mean that crop rotation will be abandoned as a practice to find new clean ground, and farms will rent less land and concentrate production on their own land.

4.5.2.1.1. Impacts on local communities

Whilst it can be argued that using foreign labour can funnel large amounts of money out of the country, a concentration of foreigners in a rural area can often bring financial benefits to local communities (Green *et al.*, 2008, Green, 2009). This has also been encountered in this study, with a number of strawberry farms employing large numbers of foreign workers. The fact that casual workers live on the farm implies that they obtain all that they need within the local area and therefore depend on local services, such as public transport, taxis and local grocery shops. Other benefits were felt slightly further away in the closest large towns, where the buying of electronic goods was very popular. Notwithstanding this, the amount of money flowing back into the local area would depend on the strength of the pound and value of local goods in relation to the price back in their country of origin. In a study on the economic impact of migrant workers on the West Midlands, it was estimated that migrants account for 5% of the regional output (Green *et al.*, 2007).

Whilst this study has provided some insight into the impact of migrant labour on the local economy, far more work is required to determine the full economic impact on local communities. The impact of currency fluctuations could also be studied, together with variations in spending and saving money between different nationalities.

4.5.3 Regional variation in the industry

Regional differences in an industry can often be caused by the nature of local challenges. This is also the case for the strawberry industry because different regions face a number of challenges that enable the growth or decline of the sector. In the case of this study, the two regions chosen were amongst the furthest physically from each other in the UK and exposed to very different challenges. The weather was predominantly different, with Kent being considerably warmer and drier than the east of Scotland. Secondly, there was the distance from the market, with Kent being on the doorstep of the biggest market in the UK (London), and Scotland being far from their main markets. With this respect, some Scottish businesses considered themselves as exporters of strawberries to England since they produce more than what the Scottish market consumes. Their main markets are in fact the big cities in the north of England.

Whilst the Kentish strawberry sector, together with Herefordshire, is seen as a pioneer in the industry, the Scottish strawberry sector lags slightly behind. The Scottish growers see themselves as slightly disadvantaged in two areas. Firstly, they get their crop about 2-3 weeks later than in the south east of England, which means that they miss out on the lucrative early season crop; and secondly, they seem to have trouble with getting the right yields of everbearer crop. The main cause of this is the weather, with Scotland having a slightly cooler and shorter season. In fact, the season in Scotland is seen to be around 4-6 weeks shorter, with 2-3 weeks on each end. This, in turn, affects the yields and actual output of the farms. Whilst the yield of large farm enterprises in Scotland was found to be the same as those in large farm enterprises in Kent, they were employing on average more casual workers per farm, sometimes collecting even less strawberries than other farms in Kent employing the same amount of workers. The average picking rate in Scotland was significantly lower than in Kent. This is bound to have an impact on the profitability of their businesses, especially since they are more reliant on the strawberry part of their business. On the other hand, they employ fewer full time staff, thus saving on extra wages. They also own larger farms, enabling them to continue rotating their crop, instead of raising it on tabletops, thus saving on the capital investment of having to introduce tabletops.

Whilst businesses in Scotland have challenges that limit their profitability, growers in Kent have other problems which are limiting their growth. The biggest problem in Kent was the rigorous planning control with regards to polytunnel usage. Being close to London has made the area popular with many wealthy commuters, who chose to settle in the Kentish countryside south of London. In fact, any growth in business in this area comes very slowly and at a huge cost because obtaining planning permission for polytunnels can be quite costly. This is a common occurrence in agricultural areas close to urban centres, and is sometimes referred to as the movement from agriculture to horsiculture (Bohnet *et al.*, 2003).

Another major problem faced by farms in Kent was soil borne disease, in particular Verticillium wilt. Growers find it increasingly hard to find clean land available due to the widespread use of hops (Harvey, 1963) and strawberries in the past. Verticillium attacks both crops; thus finding a piece of land in Kent where neither hops nor strawberries were grown in the past is quite difficult. Farms are also considerably smaller here than their equivalent in the east of Scotland, making rotation into new clean land quite difficult. This was made worse with the elimination of methyl bromide as a soil sterilant, since no other alternative fumigant has been as effective (Hancock, 1999, Medina *et al.*, 2006, Goicoechea, 2009). This again has forced farms to rent land elsewhere in other counties, or else introduce tabletops to get the plants out of the ground. This system was in fact initially introduced in response to disease contamination in soils, in particular *Phytophthora* spp. and *Verticillium* wilt (Lieten *et al.*, 2004).

Water is another limiting factor in Kent and the sector has often been faced by water bans in the past in cases of drought (Protect Kent, 2009). In Scotland, on the other hand, strawberry production is affected by other diseases, in particular red core due to the higher rainfall and clay laden soils in the area. *B. cinerea* is also a bigger problem on farms in Scotland due to the heavier rainfall. Notwithstanding this, the availability of additional land has enabled many growers in Scotland to persist using rotation.

On analysing the reasons why a farm chooses to start a business in a certain area, it was seen that hardly any of the growers moved to a certain location to resettle their business because of better land. In fact, strawberry growers tend to own most of their land and only rent a small proportion. This means that the growers tend to be tied to their land, particularly in Scotland, where they own a greater proportion of their land. This is a risk to the strawberry industry as a whole because, if businesses are struggling in a certain area rather than relocating somewhere else, they are more likely to change crop. Moreover, the recruitment rate of new farms is very small, with farms on average having grown strawberries for 32 years (median 25 years). Out of the 42 growers interviewed, less than a handful had started growing strawberries in the last 5 years, all of them in Scotland. Thus, if the industry is to survive the challenges facing it in the future, it should be allowed to adapt and use innovative techniques; otherwise, whilst more growers abandon the crop due to increasing debts, few new growers will come in to take over, and those surviving will be restricted by regulations and policies in their area. With this in mind, the strawberry sector is likely to go through another shift in geographical concentration. Kent is increasingly becoming more restrictive for the industry and, while growers there start renting land in other counties, Scottish growers are investing heavily in their businesses, increasing production in that region. Nevertheless, they are disadvantaged by their current climate which limits their yield, particularly in the everbearer varieties. This could all change with a change in climate that could shift the climatic zone by a few hundred kilometres.

4.6. SYNTHESIS

In this chapter, social science techniques have been used successfully to gather primary data on the influence of plant disease on the strawberry sector. It was seen that plant disease is nowadays not as big a threat to the strawberry sector as it was in the past. Other threats have been seen to be more important for growers, such as economic issues related to labour and price returns, and the availability of plant protection products in the future. More importantly, however, a wealth of secondary data have been generated that when combined with data collected in the previous chapters, builds a picture of how restructuring in the UK strawberry sector took place since the 1980s. Moreover, the social science study has successfully highlighted the existence of two farm types within the strawberry sector and the underlying reasons why a grower decides to belong to one and not the other.

The data generated through the social science study have also corroborated evidence gathered in previous chapters on a number of instances. Two examples in particular are:

- The Kentish strawberry sector has a particularly severe problem with Verticillium wilt (Chapter 3, Table 3-2 and Chapter 4, Section4.5.1.2.2)
- There is, nowadays, no statistical difference between the yields obtained in Scottish and English farms (Chapter 2, Figure 2-11 and Chapter 4 Table 4-10).

Whilst more such examples exist, this confirms the validity of the data generated in the social science study, as data obtained through different sources and methods arrived to the same conclusion.

Another important outcome of the social science study is that there are many circumstances where data generated in this chapter explain trends that were captured in the previous chapters, such as:

- The rapid increase in protection in 1997 has been found to be caused by three factors;
    - The introduction of Spanish tunnels by a producer in the mid-1990s (provided growers with a viable product).

- The increase in demand by supermarkets in the mid 1990s provided the demand for the crop and the need for growers to increase production and yield (thus the need for polytunnels).
- The introduction of funding schemes for producer organisations provided growers with the capital to buy the polytunnels.

In conclusion, the data generated in the social science study helped achieve the objectives outlined in the introduction to this chapter by generating a wealth of information on how the UK strawberry sector operates and the process driving decisions made by growers. Moreover, whilst plant disease was not found to be a major threat, the potential loss of plant protection products to combat plant disease was. Some in the industry even considered the impact as potentially devastating, although the extent to which it could occur was uncertain. This threat could potentially change were there to be any appreciable change in disease incidence with climate change. However, to estimate the potential threat this could cause, one has to first find out whether or not disease incidence could change in the future.

In the next chapter forecasting models for three different strawberry diseases will be developed to determine how disease incidence will change throughout the UK with climate change.

Chapter 5 Impact of climate change on strawberry diseases

5.1. INTRODUCTION

5.1.1 Impact of climate change on plant disease

In a review of impacts on disease, Harvell *et al.* (2002) suggested that climate change will affect host-pathogen interactions in a number of ways, but particularly by:

(i) increasing pathogen development rates (the number of generations per year);
(ii) relaxing overwintering restrictions on pathogen life cycles due to milder winters, higher nocturnal temperatures and higher overall temperatures; and
(iii) modifying host susceptibility to infection.

Severe winters can often limit the expansion of a pathogen beyond a certain geographical range (Garrett *et al.*, 2006) and has been known to be a major period of pathogen mortality, potentially killing more than 99% of the pathogen population annually (Harvell *et al.*, 2002). Thus a greater overwintering success of pathogens would likely increase disease severity (Coakley *et al.*, 1999, Bergot *et al.*, 2004, Stonard *et al.*, 2010) and, sometimes, even bring the outbreak of diseases earlier (Coakley *et al.*, 1999, Evans *et al.*, 2008, Gregory *et al.*, 2009). Moreover, plant species that have faster growth rates in warmer climates may also experience increased disease severity because higher host density increases the transmission of many pathogens. To add to this, increased above-ground plant biomass influences canopy humidity, which often affects foliar fungal disease spread (Harvell *et al.*, 2002). Thus changes in weather variables such as temperature, precipitation and humidity will all influence the growth, spread and survival of plant diseases, since climate and weather have a major role in influencing disease epidemiology (Rosenzweig *et al.*, 2001). This means that knowledge of how climate change will bring about specific changes in regional weather patterns is crucial in determining how plant disease outbreaks will change in the future, and potentially affect crop yields and food security.

In view of this, disease forecasting is becoming increasingly important as a tool to study the impact of climate change on plant disease. This is achieved by building disease models that are based on empirical data and can be used to predict outcomes under a range of climate change scenarios (Garrett *et al.*, 2006). The models can help provide increasingly realistic scenarios on the impact of plant diseases following changes in the magnitude and variability of temperature, precipitation and other climatic variables with climate change (Jeger and Pautasso, 2008). The outcomes can influence policy changes and target adaptation measures where and how they may be most needed. More recently, the ability to predict realistic impacts of crop disease has even been described as having implications for food security (Gregory *et al.*, 2009); it can assist in the development of more effective regional food security policies.

5.1.2 Methods used for disease forecasting

Disease forecasting in terms of climate change is usually undertaken by combining a disease model with a climate change model that predicts changes in weather. The disease models can be developed in a number of ways, two of which are the most common. The first involves the use of existing disease models or epidemiological data. The second consists of developing empirical models that use experimental disease datasets in order to determine which weather variables favour disease outbreaks. These models are then validated to match live weather events. Climate models (see definitions), on the other hand, can use either General Climate Models (GCMs)(Baede, 2007) or Regional Climate Models (RCMs)(Baede, 2007) that predict changes in weather at various spatial levels, in grid squares which can vary in scale, thus producing a geographical differentiation in changes in weather with respect to the baseline (considered to be the pre-climatic change 30-year period up to 1990-1995, depending on the model used) (Coakley *et al.*, 1999, Zwankhuizen and Zadoks, 2002, Bergot *et al.*, 2004, Hannukkala *et al.*, 2007, Booth *et al.*, 2000). The outcome usually gives a change in frequency and/or timing of plant disease impact at a specific geographical scale, with some areas being impacted more frequently and/or earlier than others, depending on the changes in the prevalent weather (Turner, 2008, Butterworth *et al.*, 2010, Stonard *et al.*, 2010).

Increasingly, more disease prediction models have been published in the last ten years (Booth *et al.*, 2000, Bergot *et al.*, 2004, Salinari *et al.*, 2006, Evans *et al.*, 2008, Turner, 2008); however, most of these studies have not considered how farmers will respond to climate change-related disease impacts by including other factors such as changes in agricultural and environmental policy, mitigation activity and consumer preferences (Barnes *et al.*, 2010). This study attempts to do this by combining the use of a disease prediction model with social science tools that attempt to collect data from agricultural stakeholders to determine how these changes in disease might impact them and how they would adapt. In this chapter, models for three different diseases are developed for Great Britain and then combined with climate change models across four different timescales (Baseline, 2020, 2050 & 2080), and three different emission scenarios (low, medium & high). The diseases used were those affecting the UK strawberry industry and included powdery mildew caused by *Podosphaera aphanis*, grey mould caused by *Botrytis cinerea*, and strawberry black spot caused by *Colletotrichum acutatum*. Whilst the first two are the two most common diseases affecting the UK strawberry industry, the third disease was a Phytosanitary disease until recently, when it was removed from the EU list of quarantine organisms harmful to plants or plant products (Anonymous, 2008) after it had become widespread in Europe and the UK.

5.2. MATERIALS AND METHODS

5.2.1 Development of the disease models

The disease models chosen for this study were weather-based disease prediction models that were built by using existing epidemiological data taken from published literature. These were used to construct a set of ideal weather conditions consisting of two or more weather variables taken over a number of days, under which conditions there is a high likelihood of disease infestations occurring. By combining these models with a climate change model, it becomes possible to study the change in likelihood of the diseases occurring and obtain an indication of the potential for disease outbreaks to occur. This method does not take into consideration management practices, which are often governed by local practices and technological developments in agriculture; thus it can be applied to wherever strawberries are grown since it focuses only on the development of the disease. Since epidemiological data from published literature were used, there was no need to collect empirical data through experiments that would first need to be validated before they could be used. Moreover, the data referenced were already validated through experiments carried out by the authors of the published literature, thus no further validation was done for this study.

Whilst being simplistic in form, these models assume that inoculum is present equally throughout the region, and the only factor varying is the weather, while everything else is constant. In a real case scenario, even though the predictions of disease potential might be valid, the likelihood of actual outbreaks occurring would depend on the availability of inoculum.

The models were built using GenStat® 12th edition and when combined with the climate change models, could search for a set of specific weather events through daily records of weather over a 30 year period, and then display the outcome in terms of the mean number of disease occurrences per year.

5.2.1.1. Model for Powdery mildew caused by *Podosphaera aphanis*

The development of this disease can be relatively rapid, with the appearance of the first disease symptoms following inoculation after only four days (Amsalem *et al.*, 2006). The optimal temperature range for conidial germination and conidial germ tube length ranges approximately between 15 and 27°C (Xiao *et al.*, 2001, Blanco *et al.*, 2004, Amsalem *et al.*, 2006). There are differences in opinion, however, as to the optimal relative humidity levels required. Blanco *et al.* (2004), following a set of field based experiments, suggest a relative humidity of less than 70% and a rainfall of less than 5mm or none at all. Xiao *et al.* (2001), who compared results between experiments in the open field and under polytunnels, suggest a moderate to high relative humidity without free moisture, whilst Amsalem *et al.* (2006), who carried out experiments in a growth chamber, found the optimal relative humidity to be higher than 75%, but less than 98%.

Following consideration of published literature, the following conditions were chosen for the model:

- Time sequence: one week (7 days) in order to allow disease to develop and show symptoms.
- Temperature range: daily maximum temperature >= 15^{o}C & < 28^{o}C for 7 consecutive days
- Relative humidity: > 70% for 7 consecutive days
- Rainfall: total rainfall over a 7 day period to be < 5mm.

The analysis of climate/weather data identified the number of occasions on which the temperature range, relative humidity and total rainfall coincided with the above list over the same consecutive seven-day period. Whilst the temperature range was easier to choose since most epidemiological studies agreed, the relative humidity and rainfall were slightly more problematic. The model was targeted to look for events with a high relative humidity and low rainfall over a slightly prolonged period, that is highly characteristic of the ideal conditions required for powdery mildew to thrive in strawberries.

5.2.1.2. Model for Grey Mould caused by *Botrytis cinerea*

The development of grey mould in strawberries is favoured by cool (15^{o}C to 25^{o}C), wet weather (Maas, 1998) and high humidity (Xu *et al.*, 2000) with the incidence of infection increasing from near zero to more than 90% as the duration of leaf wetness increases from six to 24 hours (Maas, 1998). Conidia are mostly released in response to increasing relative humidity, leaf vibrations and, in particular, splashing rain droplets which then become coated with the conidia (Sutton, 1990).

Following consideration of published literature the following conditions were chosen for the model:

- Time sequence: two days in order to allow high infection rates at the ideal temperature conditions
- Temperature range: daily maximum temperature between 15^{o}C and 25^{o}C for two consecutive days
- Relative humidity: > 90% for two consecutive days
- Rainfall: daily rainfall of at least 1mm for two consecutive days.

The analysis of climate/weather data identified the number of occasions on which the daily maximum temperature, relative humidity and total rainfall coincided with the above list over the same consecutive two-day period. The choice of the temperature range coincides with published literature, whilst the combination of high relative humidity and rainfall of at least 1mm provides the high leaf wetness conditions that enable rapid infection. The 1mm rainfall threshold was chosen to concur with what the UKCP09 consider as a rainy day i.e. one having a precipitation of >= 1mm, thus in this case, two days of consecutive rain.

Frost damage during the growing season is considered as one of the factors affecting the susceptibility of strawberry plants to attack by *Botrytis cinerea* (Maas, 1998). To investigate the potential change in the occurrence of frost during the growing season, a separate model that predicts the number of days with frost during the growing season (March to October both months included) was developed. Frosty days were taken according to UKCP09 as days when the average minimum temperature (Tmin) is below 0^{o}C.

5.2.1.3. Model for strawberry black spot caused by *Colletotrichum acutatum*

Wharton and Diéguez-Uribeondo (2004) identify seven essential stages of the infection process and fungal development for all *Colletotrichum* species. In the first stage, germination occurs within three hours after inoculation (Leandro *et al.*, 2001), and is favoured by continuous wetness at nearly 100% relative humidity (Maas, 1998, Wilson *et al.*, 1990), at an optimum temperature range of 23.0 to 27.7^{o}C and is very low when daily wetness periods are less than four hours (Leandro *et al.*, 2003). In the remaining stages, the key environmental variable is temperature, which should range from around 20 to 32^{o}C (Leandro *et al.*, 2003, Maas, 1998), with the optimal sporulation levels occurring at 22 to 26^{o}C (King *et al.*, 1997).

Following consideration of published literature, the following conditions were chosen for the model:

- Time sequence: three days since according to literature, under ideal temperature conditions and high initial humidity levels, conidiation would occur within three days of inoculation (King *et al.*, 1997, Leandro *et al.*, 2003).
- Temperature range: daily maximum temperature between 20^{o}C and 32^{o}C for three consecutive days
- Relative humidity: > 95% for the first of three consecutive days since high humidity is needed for germination of the conidia in the first stage of development of the pathogen.

The analysis of climate/weather data identified the number of occasions on which the daily maximum temperature and relative humidity coincided with the above list over the same consecutive three-day period. The choice of the temperature range and high relative humidity coincides with the published literature. On the other hand, precipitation was not considered for three reasons. The first is that the assumption that the inoculum is already present is being made, and rainfall only affects dispersal of the conidia after sporulation and not infection or germination; thus once conidia are present there is no need for rain for the infection to be triggered. Secondly, following evidence from Chapter 3, it was observed that trade in infested plants was the main reason for the dispersal of the diseases throughout the UK. Thirdly, in a study by Ureña-Padilla *et al.* (2001) inoculum of *Colletotrichum* was found not to survive in buried plant debris between seasons; thus the disease survives either as a latent infection in the plant (Wharton and Diéguez-Uribeondo, 2004), or comes back to the field through trade of infested plants, making rainfall irrelevant in its regional dispersal.

5.2.2 Use of a climate model

The UK Climate Projections (UKCP09) (Murphy *et al.*, 2009) were used in this study to project changes in weather variables for three different time frames (2020, 2050 & 2080) under three emission scenarios. These emission scenarios are taken from the Special Report on Emission Scenarios (SRES) (Nakicenovic *et al.*, 2000) and are developed from two storylines: the A1 (two scenarios) and the B1 storyline (one scenario). In the UKCP09, these emission scenarios are labelled according to their relative greenhouse gas emissions levels – High (SRES A1FI), Medium (SRES A1B1) and Low (SRES B1) (Murphy *et al.*, 2009). The probabilistic climate change projections arise from modelling of the Met Office Hadley Centre climate model HadCM3 that uses perturbed physics ensembles (PPE) to generate climate projections (Murphy *et al.*, 2009). The projections also include results of other IPCC climate models and are constrained by observations of past climate. Moreover, each projection of future climate change is given relative to the modelled climate during a baseline period (1961-1990), which serves as a reference.

The UKCP09 also uses the Met Office regional climate model (RCM) to downscale global climate projections to a 25 km scale, thus providing finer detail in projections at a local scale. The whole UK territory is divided into 434 of these 25km grids. Notwithstanding the detail, the probabilistic projections only provide monthly means of climate variables. This would be problematic since the disease models developed in this study make use of daily weather datasets.

In order to obtain a higher temporal resolution and daily weather data, the UKCP09 Weather Generator was used. This weather generator "is based around a stochastic rainfall model that simulates future rainfall sequences. Other weather variables are then generated according to the rainfall state. Statistical measures within the Weather Generator are then modified according to the probabilistic projections developed in UKCP09." (pg 8)(Jones *et al.*, 2009). The weather generator has the advantage of providing a high resolution time series of weather variables at higher spatial resolution of a 5 by 5 km grid square. The variables generated were temperature rainfall, humidity and amount of sunshine.

For the purpose of this study, the probabilistic projections were produced as a multiple (100), daily time series of 30 years in length which are "statistically equivalent" and "stationary"[18] (Jones *et al.*, 2009). With every run, to validate these probabilistic projections, the weather generator also produced a control of 100 statistically equivalent daily time series of 30 years in length, which represent the baseline years of 1961-1990. These were to be used as a control. Each 30 year time series is downloaded as a separate csv file, such that every request generated 200 files were obtained in a folder: 100 for the control and 100 for the future period.

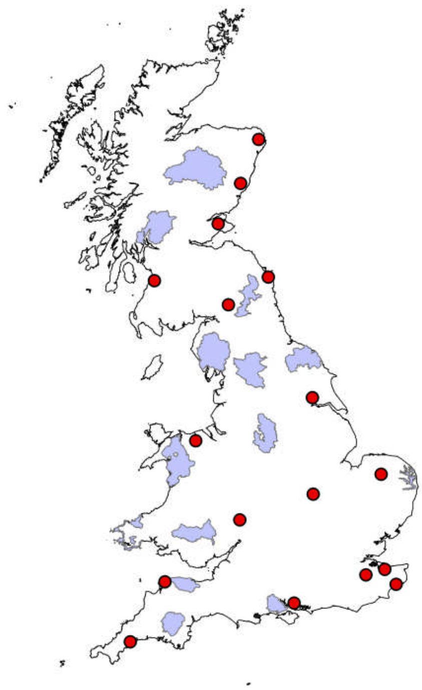


Figure 5-1 Locations of sites chosen for downloading probabilistic projections (red dots). The Scottish Highlands (Northwest half of Scotland) and National parks (areas shaded in grey) were avoided.

17 sites were selected that were roughly equally distributed throughout the UK (Figure 5-1). The sites were chosen to coincide with locations which are known to be used for strawberry cultivation, or have been in the past. Regions with higher altitudes where strawberry cultivation is not feasible were not chosen as candidate

[18] "Stationarity means that they will contain realistic day-to-day and year-to-year weather variability, but there will be little variation in the statistical description of that variability over the long term (i.e. the climate)." As defined on pg 8 of Jones *et al*., (2009).

sites for downloading probabilistic projections. For Kent, three sites were chosen to test the intra-county variation and also for extra detail since that county has been a centre of strawberry production and a hotspot for several disease epidemics. The data for these 17 sites were downloaded using the weather generator. Since through the weather generator, the generated climate variables are at a 5 km resolution that are consistent with the underlying 25 km resolution climate projections, no two locations were taken which coincided within the same 25 km grid.

Table 5-1 Locations of the sites for which probabilistic projections were downloaded using the weather generator

Location	County
Auchincruive	Ayrshire
Carnforth	Lancashire
Cupar	Fife
Denbigh	Wales
East Dereham	Norfolk
Ellingham	Northumberland
Fareham	Hampshire
Faversham	Kent
Folkestone	Kent
Geddington	Northamptonshire
Ilfracombe	Devon
Laurencekirk	Kincardineshire
Ledbury	Herefordshire
Maidstone	Kent
Mevagissey	Cornwall
Peterhead	Aberdeenshire
South Cliffe	Yorkshire

5.2.3 Data analysis

In all, nine scenarios and nine controls were produced for each of the 17 sites. The probabilistic projections were then combined with the three disease models using

GenStat® 12th edition, which enabled the programme to open and run the 200 csv files simultaneously to determine the mean number of times the disease is highly likely to occur each year per run[19]. Each scenario run was stored in datasets, as 100 statistically equivalent values of the mean number of disease incidences that are expected to occur each year. Since the nine controls downloaded per site are statistically equivalent, and all represent the same baseline years, only the results from one control run chosen at random, were used.

The mean values for the 100 runs were summarised using a boxplot for each scenario for each location to show the inherent variability between years and scenarios. In most cases though, the median of the summary values across the 100 runs for each probabilistic projection, were calculated, and either plotted for each location using ArcGIS 9 (ArcMap 9.2) or else graphically portrayed through a scatter plot. On comparing the different timescales and scenarios, it was possible to obtain the change in likelihood of the disease occurring, together with the reason for the change (the responsible weather variable). On some occasions, only the medium emission scenario using the A1B1 storyline was used since this was considered by the UKCP09 to be most robust (Murphy *et al.*, 2009).

In order to study spatial variation in the disease forecasts, the median values for each location were interpolated using an ordinary Kriging Interpolation[20] (ArcGIS, 2009) using a spherical semivariogram model. To do this, the values for each of the 17 sites, under one climate projection were plotted and then spatially interpolated to observe the change in likelihood of the disease occurring under each scenario throughout Great Britain.

To test the significance of the difference in the disease predictions between the various scenarios and years for each site, a general analysis of variance was conducted using GenStat® 12th edition. The mean values for the 100 replicate runs per probabilistic projection were analysed, by comparing them across scenarios and with the control, for each site. An ANOVA was also done across the sites, timeframes and scenarios for each disease. The variance ratios were also calculated.

[19] Due to the stationarity of the data, there is no statistically significant long term variability present within a 30 year run. Therefore the mean number of yearly incidences for each 30 year run was used as a summary statistic. As a result 100 different means were obtained per probabilistic projection.
[20] Kriging uses information about the correlation/covariance between points at different separation distances (to produce a variogram) and then uses this information to generate the interpolated surface.

5.3. RESULTS

In this section, the impacts of climate change on the three diseases will be discussed separately. Spatial and temporal change in disease incidence will be discussed and the significance of results is assessed. The results are also displayed graphically and pictorially by means of maps.

5.3.1 Impact on potential incidence of Powdery mildew

Incidence of powdery mildew in strawberries was predicted to increase under climate change projections across most of Great Britain, with disease incidence increasing more in Scotland, Western Wales and the north of England. Increases over time were also observed, with a progressive increase in incidence occurring from 1990 to 2080 across most of Great Britain, except for a slight decrease in 2080 in potential disease incidence in southeast England under the MES and HES when compared to the baseline (Figure 5-3). ANOVA carried out for each site per time frame confirmed that the probabilistic projections across the time series were significantly different for 14 of the 17 investigated sites. ANOVAs for mean number of potential incidence events per year, across the different emission scenarios, were found to be significantly different in just over half of the sites (10 of the 17 sites), suggesting that the effect of the emission scenario on future potential disease incidence is less influential than the time factor. On performing an analysis of variance across sites as well as time frames and emission scenarios, significant effects of the timeframes (years) (F.pr.<0.001; v.r[21]=212.36), emission scenarios (F.pr.<0.001; v.r=8.42) and locations (F.pr.<0.001; v.r=56.81) were obtained. Moreover, important interactions were obtained between timeframes and emission scenarios (F.pr.<0.001; v.r=6.80), locations and timeframes (F.pr.<0.001; v.r=38.69), locations and emission scenarios (F.pr.<0.001; v.r=3.12) and the full interaction[22] (F.pr.<0.001; v.r=2.18). The variance ratio obtained for emission scenarios was smaller than that obtained for the timeframes, confirming that the effect of the emission scenario on future potential disease incidence is less influential than the time factor.

[21] Gives an indication of the variation within the means of a factor, i.e. the variation obtained between the means obtained for the different time frames, or the different locations.
[22] Variance ratio indicates variations within the factor, e.g. Interactions between Locations and timeframes suggests that there was variation in the potential disease incidence between the timeframes obtained for the different locations.

In almost all of the cases where an increase in potential disease incidence was recorded, the driving factor was an increase in summer temperature or, more specifically, an increase in the number of occasions where the temperature fell within the ideal 15 to 27^{o}C conducive to the development of the disease. Only on one occasion, for Cornwall, was an increase in potential incidence of mildew linked to another weather variable - a decrease in summer rainfall.

One of the outcomes of the probabilistic projections was the increased variability between climate projection runs when compared to the baseline. This variability increased for all projections for all the sites (Figure 5-4), implying that whilst the median number of outbreaks will increase in most of Great Britain, the actual number of outbreaks from year to year can vary drastically, from years with very low disease outbreaks to years with potential epidemics to an extent that was not previously seen during the baseline years.

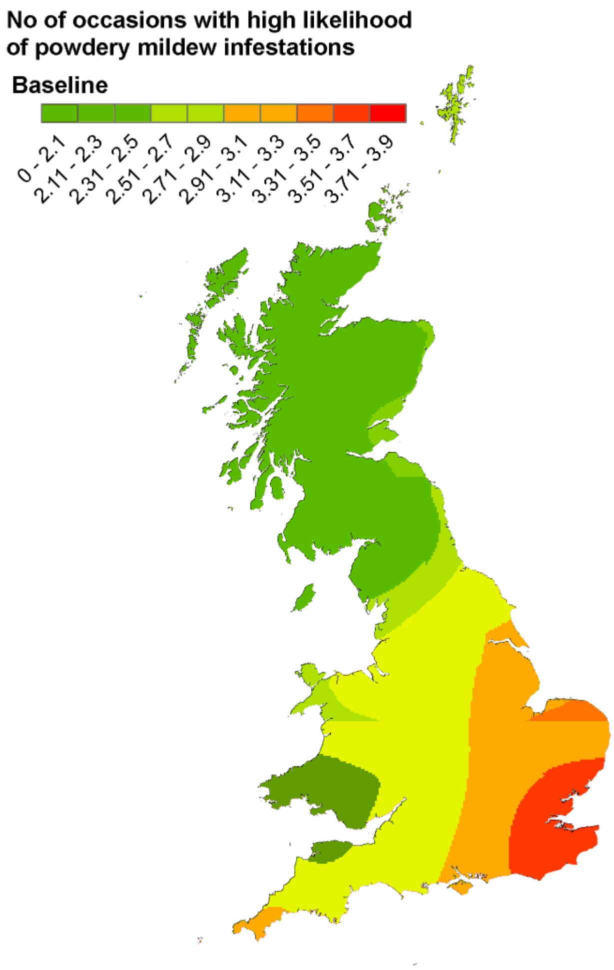


Figure 5-2 *Map showing Kriged values of the potential yearly incidence of powdery mildew for the baseline years.*

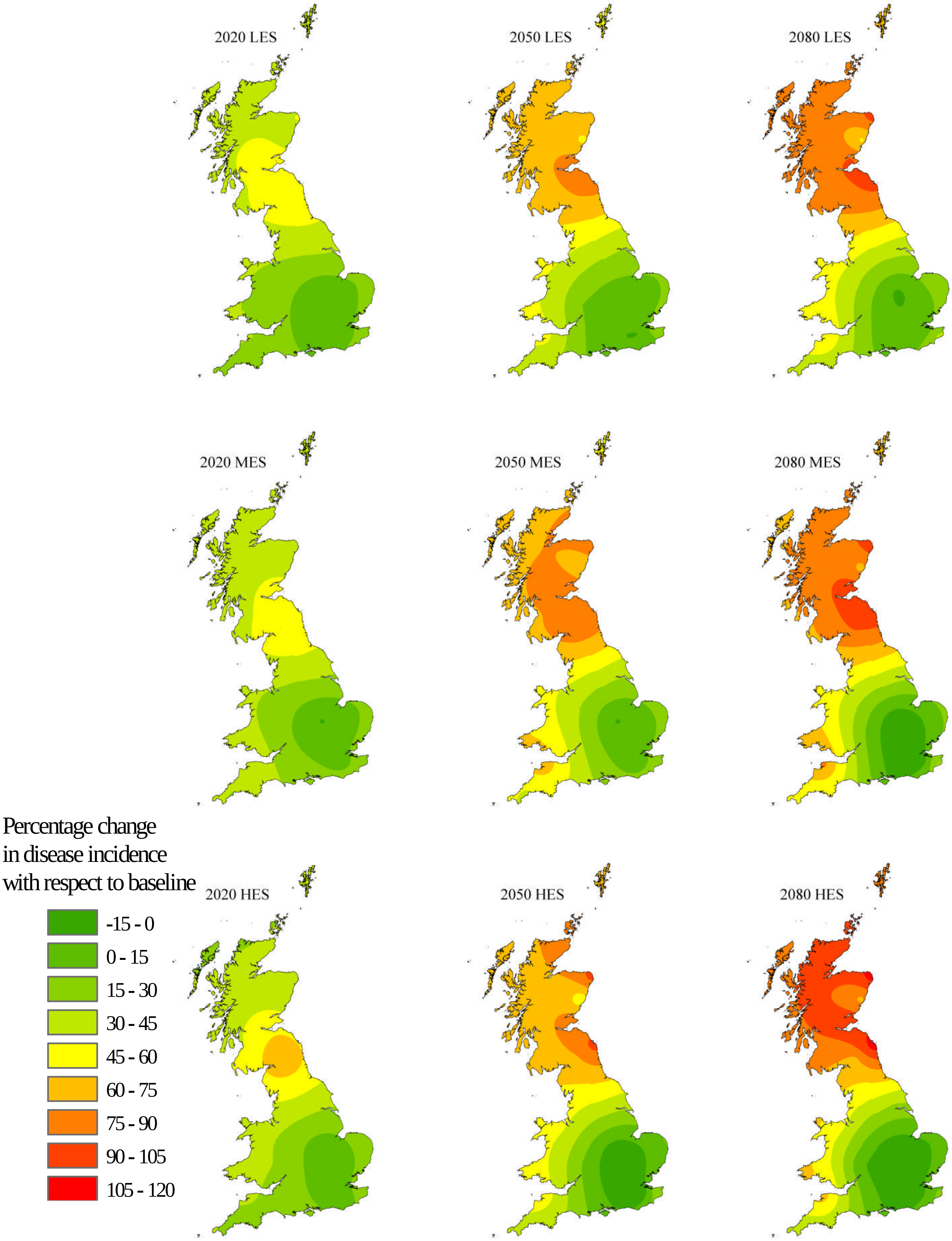
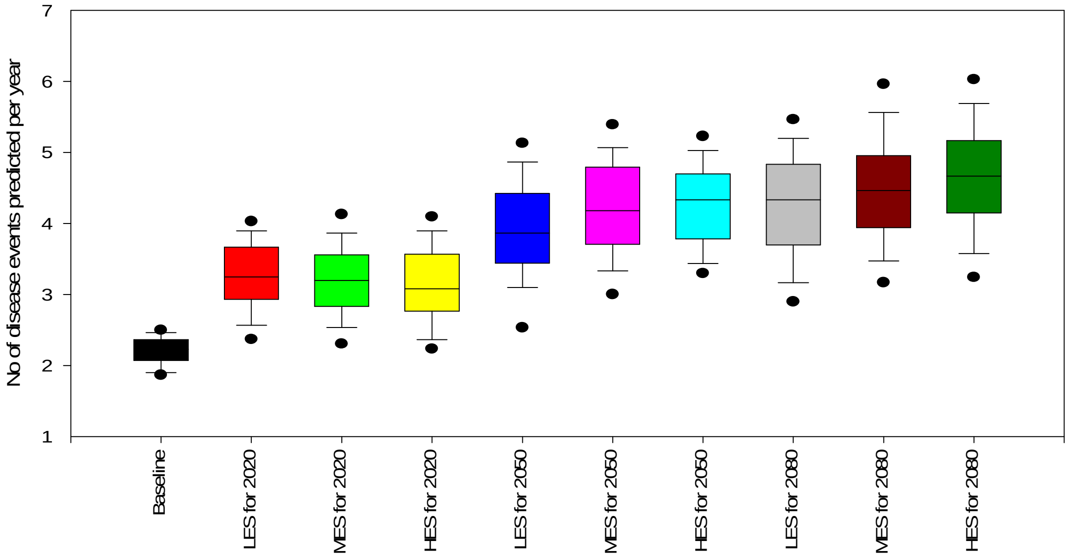


Figure 5-3 Map showing kriged values of the percentage change in potential incidence of powdery mildew between each scenario median and the control median (baseline see Figure 5-2) for 2020 (left column), 2050 (middle column) and 2080 (right column), with three different emission scenarios: LES (first row), MES (second row) and HES (third row).



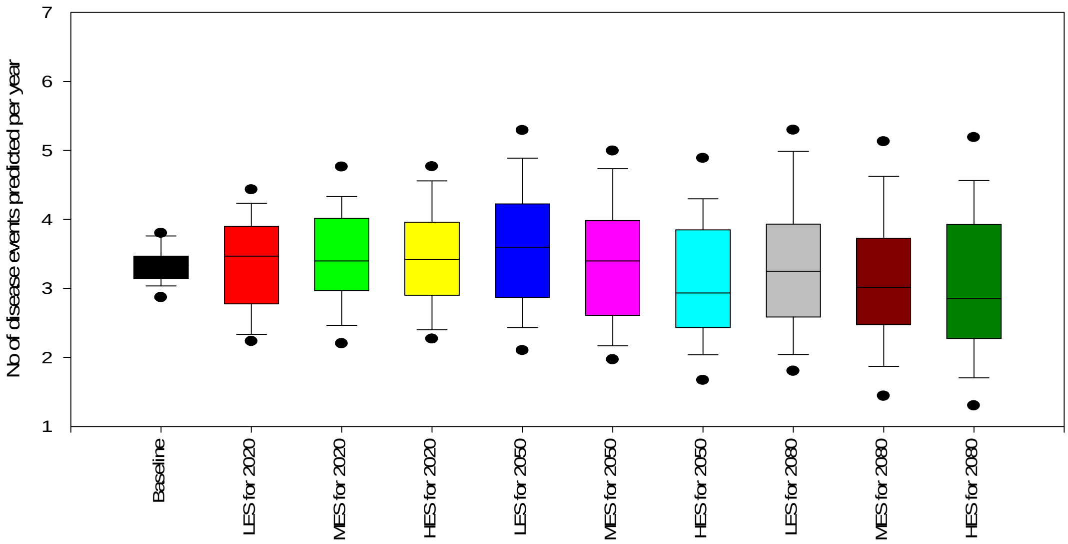
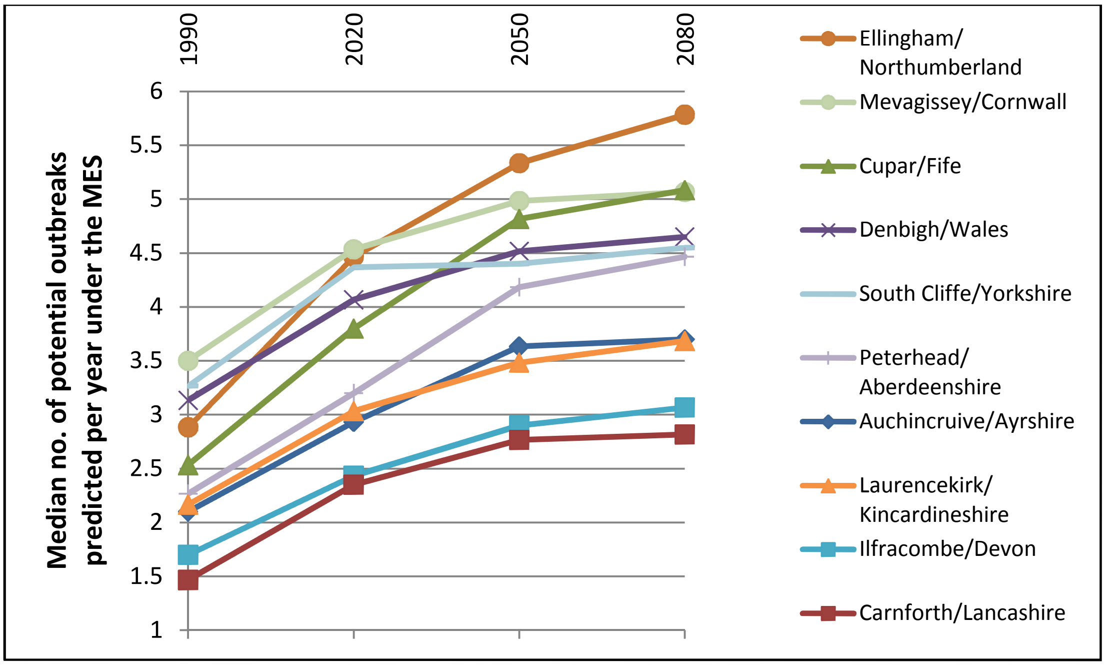


Figure 5-4 Box plots of the nine probabilistic projections at the various scenarios for two sites; Peterhead, Aberdeenshire above and Geddington, Northamptonshire below. Each box-plot contains the mean number of potential events per year, summarised for the 100 runs for each scenario. The central mark in the box is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the 5th and 95th percentiles.

The increases in incidence of powdery mildew in the north and west of Great Britain will gradually bring a shift in the distribution of the disease frequency as the North-east of Scotland becomes more suitable for the development of powdery mildew epidemics (Figure 5-5). Regions such as Scotland, which previously were limited by lower temperatures would overtake areas such as Kent, which in the baseline years offered the best climate for the development of powdery mildew epidemics.



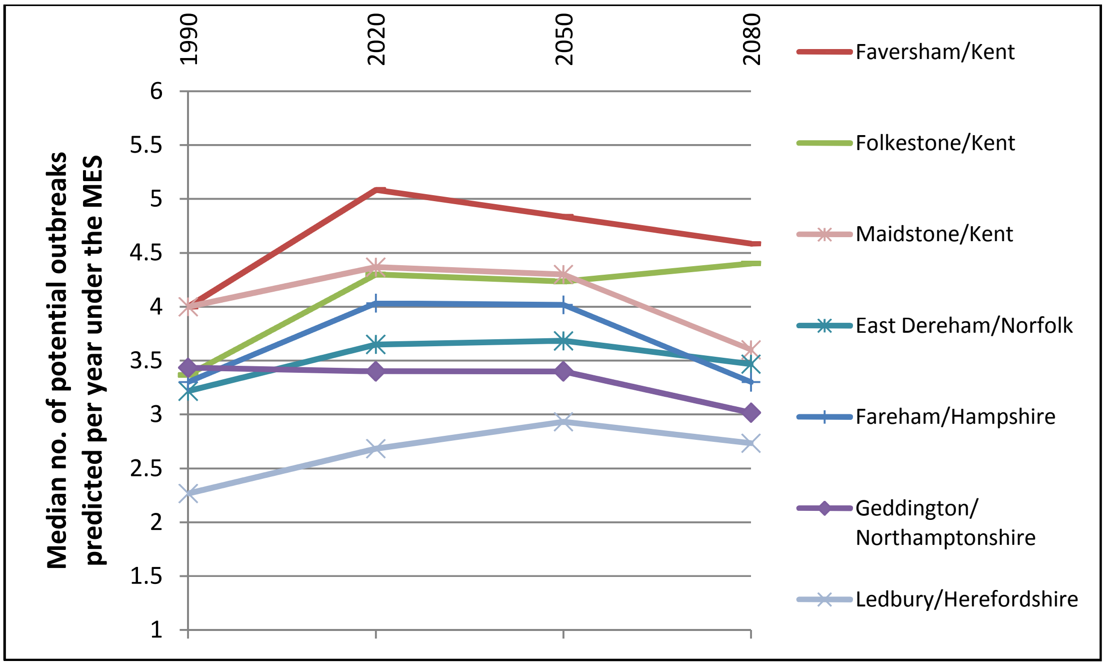


Figure 5-5 Two scatter plots showing the predicted median number of potential outbreaks per year under the various timeframes under the A1B1 storyline (MES) for the north and west of Great Britain (top) and the south east of England (bottom).

5.3.2 Impact on potential incidence of grey mould

Potential incidence of grey mould was predicted to change across most of Great Britain, with increases north of the Midlands and slight decreases everywhere else particularly in southern Great Britain (Figure 5-8). Moreover, where increases in potential disease incidence are predicted, the fastest increases will occur up till 2020 and then fall back by 2050 and 2080. ANOVAs carried out for each site per time frame confirmed that the probabilistic projections across the time series were significantly different in 14 of the 17 sites investigated. ANOVAs for mean number of potential incidence events per year, across the different emission scenarios were found to be significantly different in only 3 of the 17 sites, suggesting that the effect of the emission scenario on future grey mould disease incidence is less influential than the time factor. On performing an analysis of variance across sites as well as time frames and emission scenarios, significant effects of the timeframes (years) (F.pr.<0.001; v.r=149.44) and locations (F.pr.<0.001; v.r=25.92) were obtained. Moreover, important interactions were obtained between timeframes and emission scenarios (F.pr.<0.001; v.r=15.59), locations and timeframes (F.pr.<0.001; v.r=3.03) and the full interaction (F.pr.<0.001; v.r=1.77).

Where an increase in potential disease incidence was recorded, the driving factor was found to be the increase in number of occasions when the ideal conditions for temperature were achieved, particularly for regions where botrytis is still limited by low temperatures, such as in Scotland and in the North of England. In fact, as the temperature is predicted to rise, the potential disease incidence also rises in these areas, until 2020. Beyond this, the continued increase in temperature is followed by a decrease in the number of occasions when the ideal rainfall and humidity levels are achieved, leading to a drop in the number of predicted potential disease incidences. In regions where the potential disease incidence decreased, this was linked to a decrease in the number of occasions when the ideal humidity levels were obtained. The number of years in each 30 year run, where no frost was achieved during the growing season of March to October, also decreased with time, particularly in the south and west of Great Britain, further affecting the potential incidence of grey mould caused by frost damage on strawberry plants (Figure 5-6).

One of the outcomes of the probabilistic projections was the increased variability between climate projection runs when compared to the baseline. This variability increased for all projections for all the sites (Figure 5-9), implying that whilst the median number of outbreaks will increase in most of Great Britain, the actual number of outbreaks from year to year can vary drastically, from years with very low disease outbreaks to years with potential epidemics to an extent that was not previously seen during the baseline years.

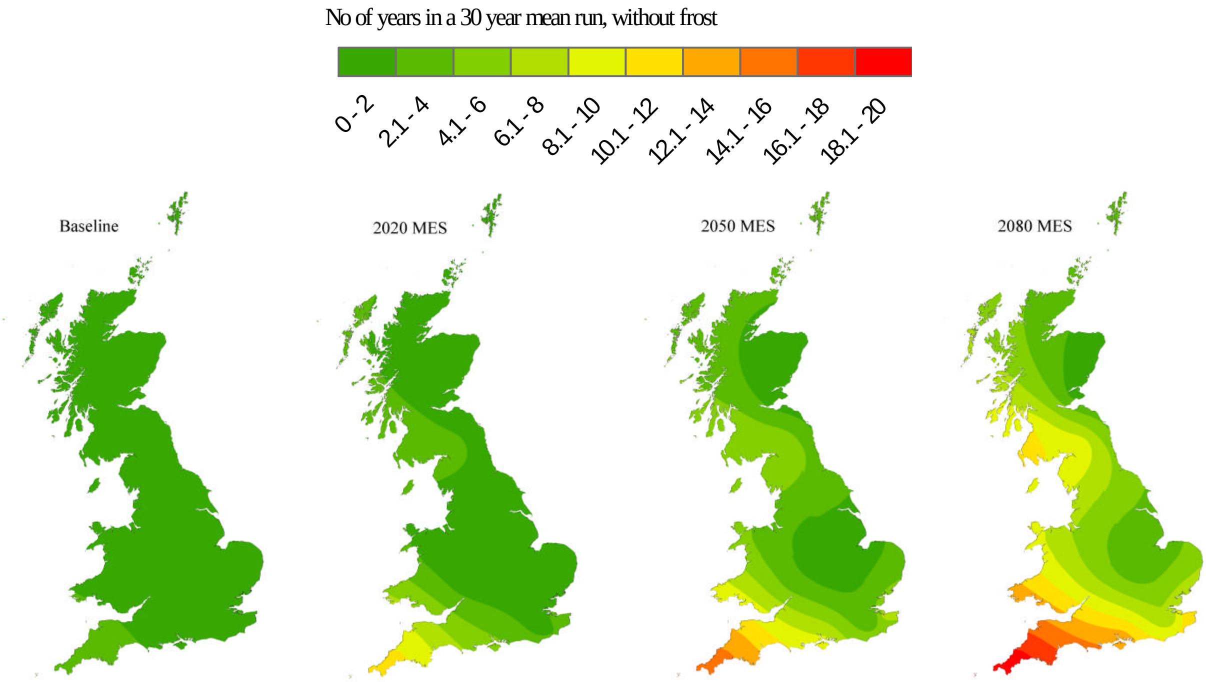


Figure 5-6 Map showing kriged values of the median number of years in a 30 year run without frost (T_{min} < $0^{o}C$) forecasted in the growing season from March to October for the baseline, and for the three probabilistic projections of climate change for the A1B1 storyline.

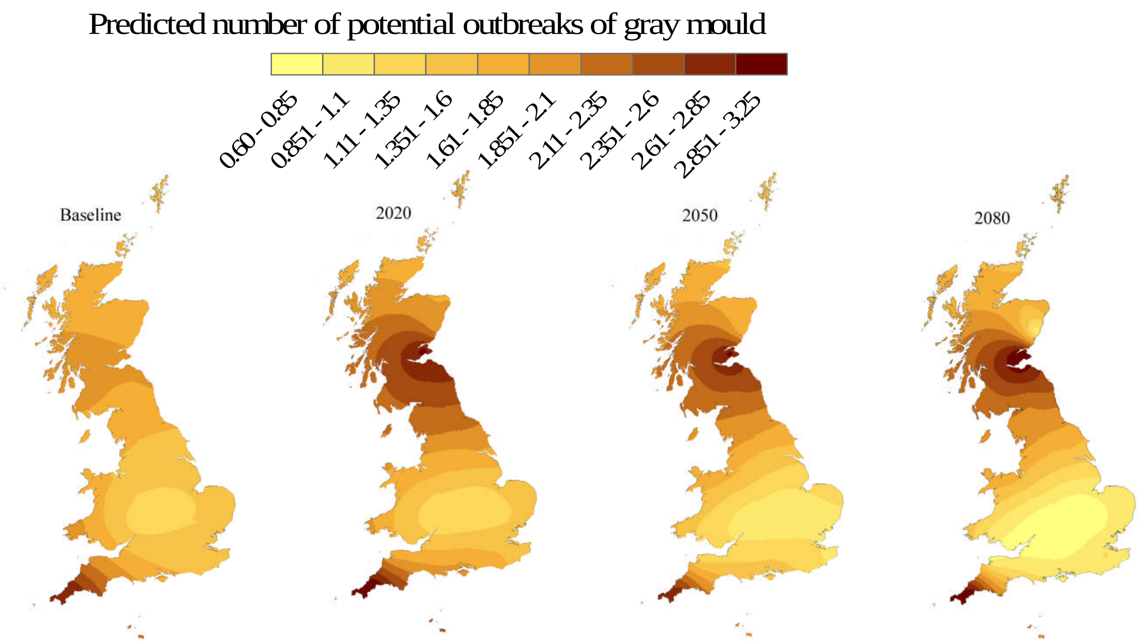


Figure 5-7 Map showing kriged values of the predicted number of potential outbreaks of grey mould in strawberry per year in Baseline climatic conditions and under the A1B1 storyline (MES) for 2080.

The changes in potential incidence of grey mould in strawberry across Great Britain will gradually bring a shift in the distribution of the potential disease frequency as the southeast of Great Britain becomes less suitable for the development of grey mould epidemics, and the north-east of Scotland gradually becomes the region with the highest likelihood of the disease occurring (Figure 5-7).

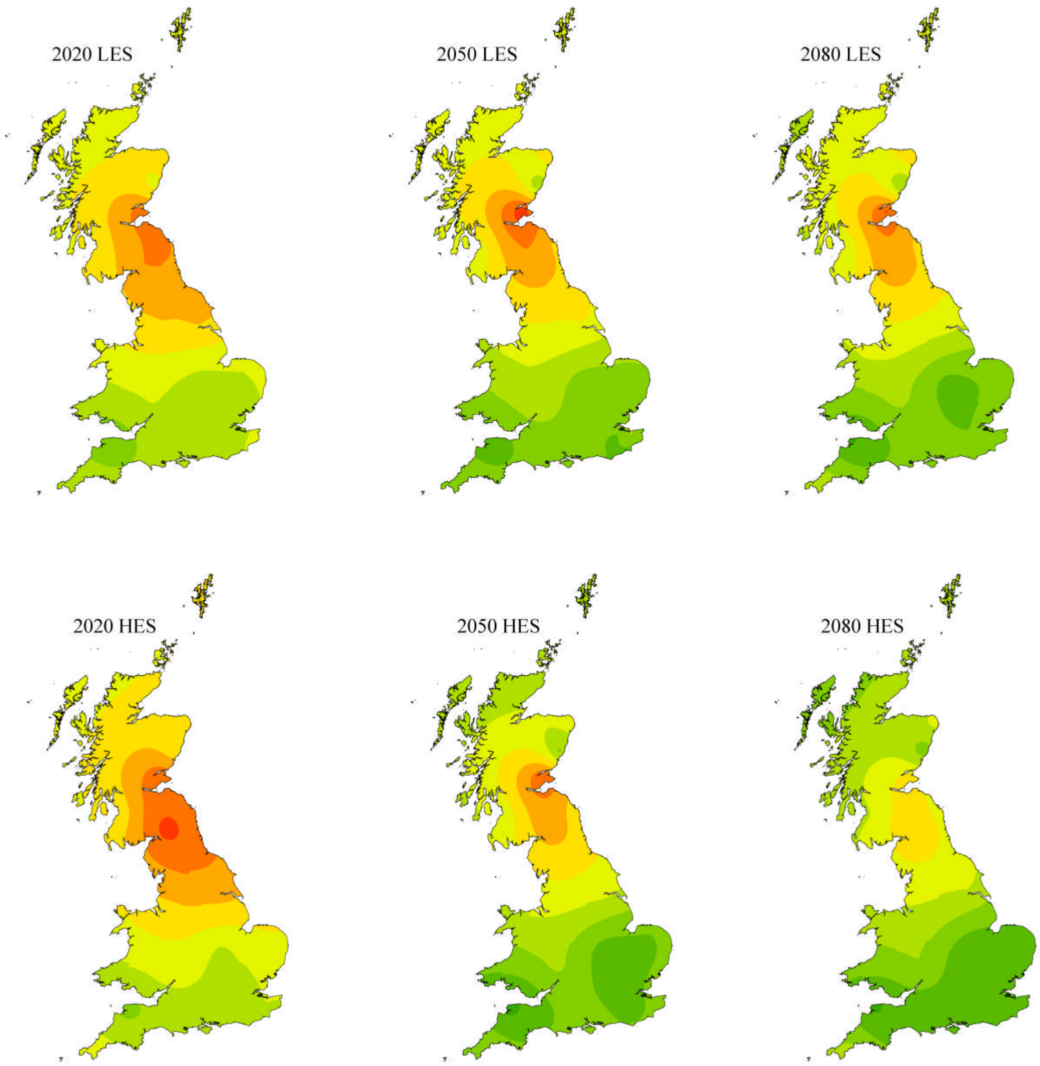


Figure 5-8 Map showing kriged values of the percentage change in potential incidence of grey mould between each scenario median and the control median (for baseline see Figure 5-7) for 2020 (left column), 2050 (middle column) and 2080 (right column), with two different emission scenarios: LES (first row) and HES (second row).

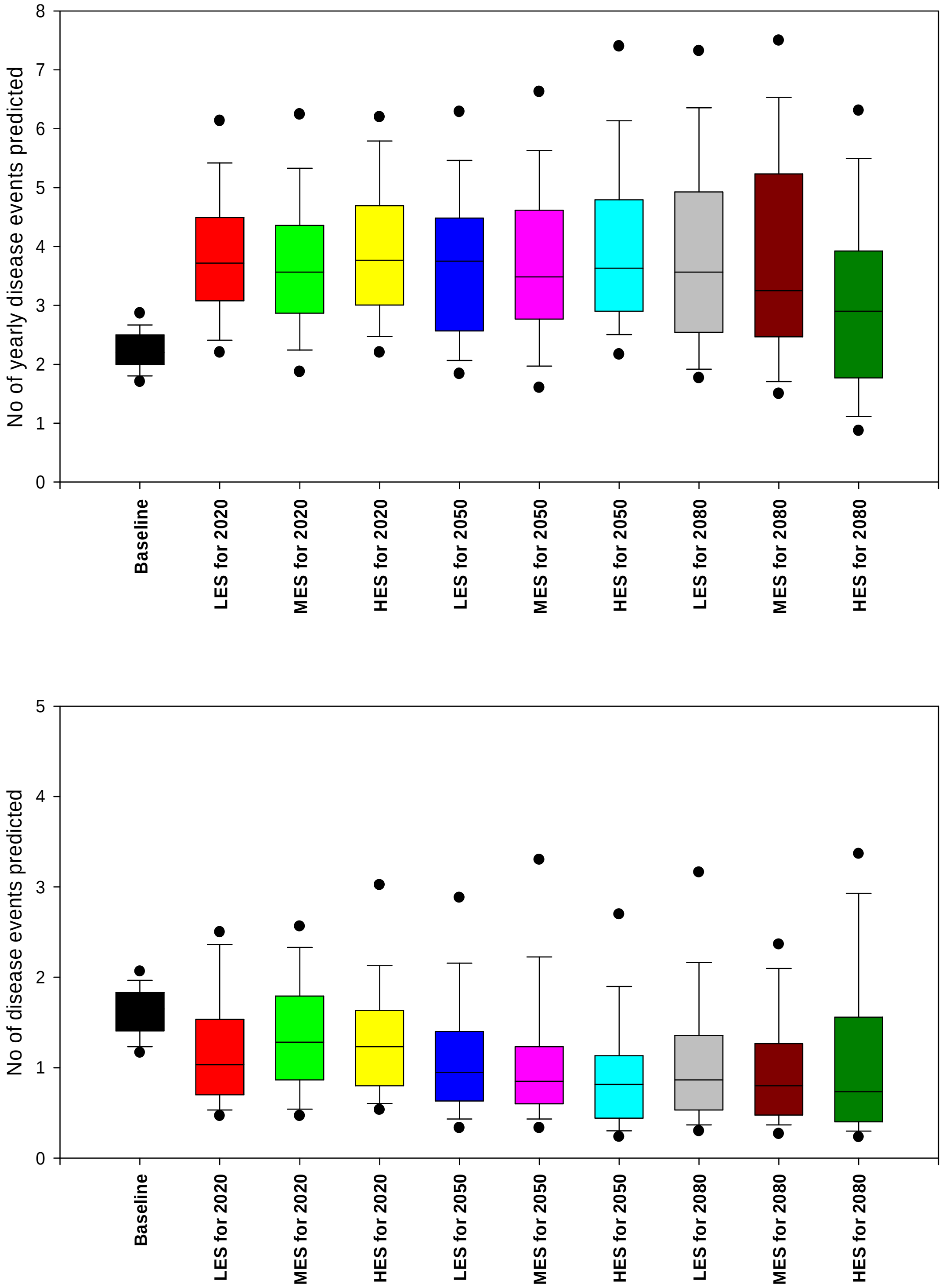


Figure 5-9 Box plots of the nine probabilistic projections at the various scenarios for two sites; Cupar, Fife above and Ilfracombe, Devon below. Each box-plot contains the mean number of potential events per year, summarised for the 100 runs for each scenario. The central mark in the box is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the 5th and 95th percentiles.

5.3.3 Impact on potential incidence of strawberry black spot

Incidence of strawberry black spot was predicted to increase drastically across most of Great Britain, with potential disease incidence increasing most in Scotland and around the West coast of Great Britain. Increases along the time frames were also observed in these same areas, whilst the Midlands and south east of Great Britain experienced an increase in disease incidence only until 2020 (Figure 5-11). ANOVA carried out for each site per time frame confirmed that the probabilistic projections across the time series were not significantly different in only 4 of the 17 sites investigated, all of which were located in the Midlands or south east Great Britain. ANOVAs for probabilistic projections across the different emission scenarios were significantly different in just over half of the sites (10 of the 17 sites), suggesting that the effect of the emission scenario on future potential disease incidence is less influential than the time factor. On performing an analysis of variance across sites as well as time frames and emission scenarios, significant effects of the timeframes (years) (F.pr.<0.001; v.r=508.29), emission scenarios (F.pr.<0.001; v.r=46.75) and locations (F.pr.<0.001; v.r=27.91) were obtained. Moreover, important interactions were obtained between timeframes and emission scenarios (F.pr.<0.001; v.r=16.21), locations and timeframes (F.pr.<0.001; v.r=27.37), locations and emission scenarios (F.pr.<0.001; v.r=2.23) and the full interaction (F.pr.<0.001; v.r=2.27). The variance ratio obtained for emission scenarios though was smaller than that obtained for the timeframes, confirming that the effect of the emission scenario on future potential disease incidence is less influential than the time factor.

In the cases where an increase in potential disease incidence was recorded, the driving factor was found to be an increase in the number of occasions where the temperature fell within the ideal temperature range conducive to the development of the disease.

One of the outcomes of the probabilistic projections was the increased variability between climate projection runs when compared to the baseline. This variability increased for all projections for all the sites (Figure 5-12), implying that whilst the median number of outbreaks will increase in most of Great Britain, the actual number of outbreaks from year to year can vary drastically, from years with very low disease outbreaks to years with potential epidemics to an extent that was not previously seen during the baseline years.

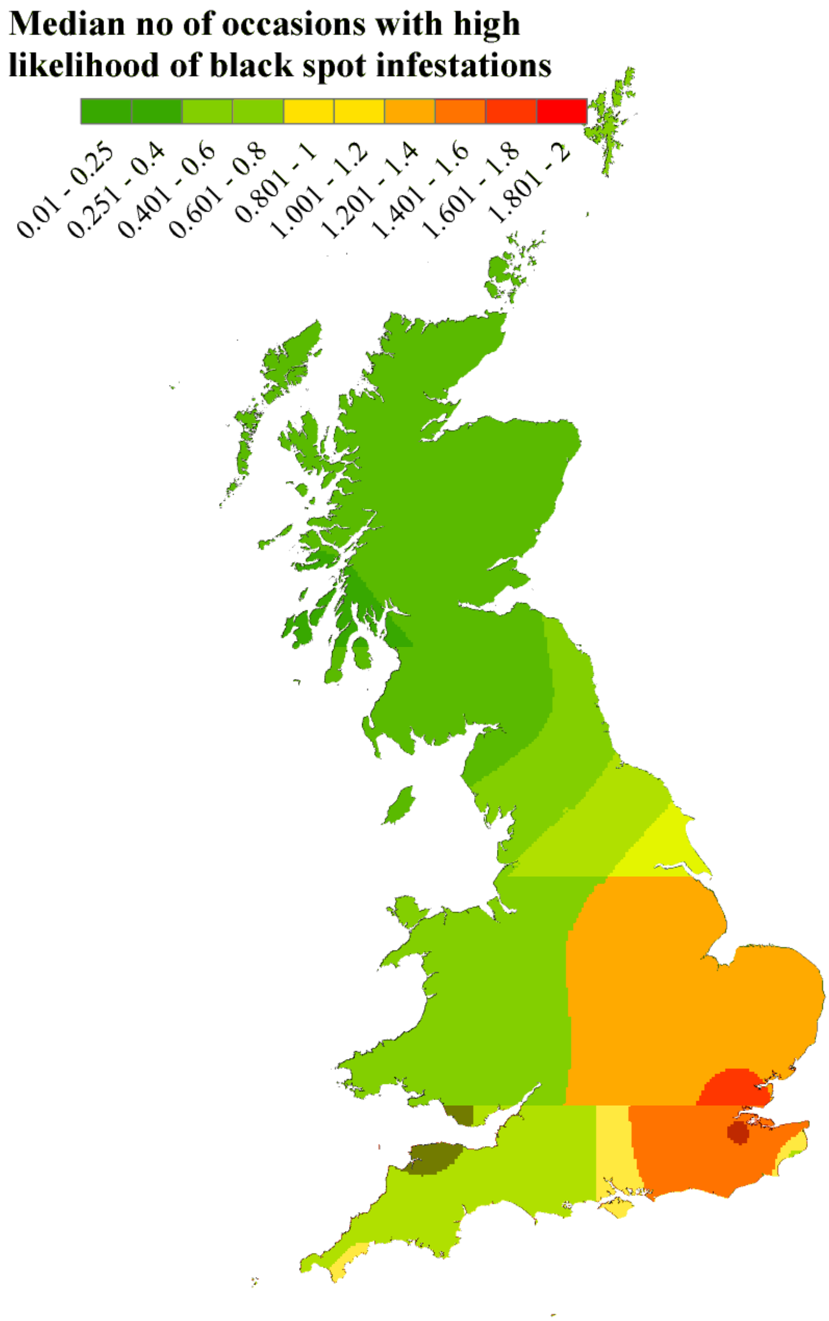


Figure 5-10 Map showing Kriged values of the potential yearly incidence of strawberry blackspot for the baseline years.

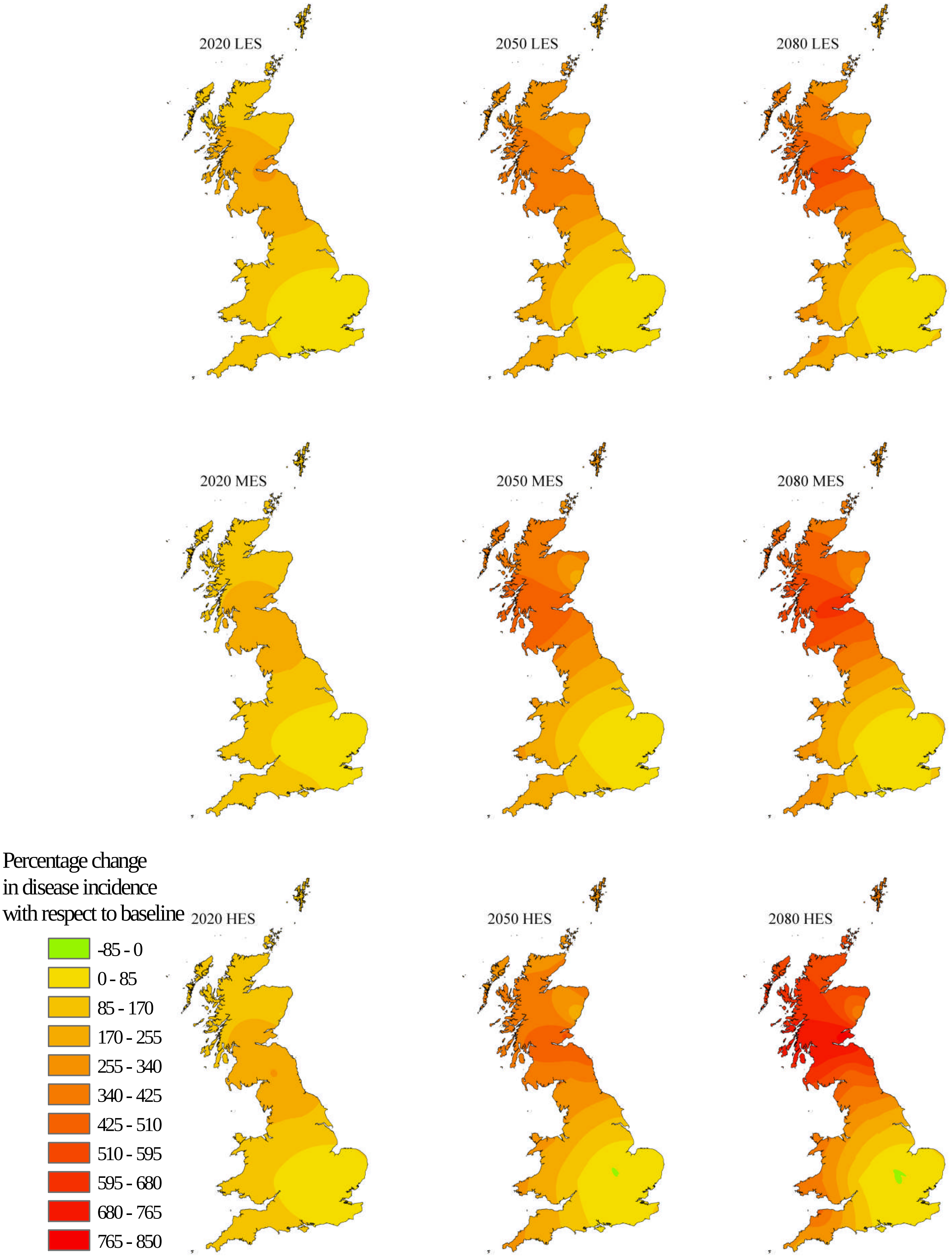


Figure 5-11 Map showing kriged values of the percentage change in potential incidence of strawberry black spot between each scenario median and the control median (baseline see Figure 5-10) for 2020 (left column), 2050 (middle column) and 2080 (right column), with three different emission scenarios: LES (first row), MES (second row) and HES (third row).

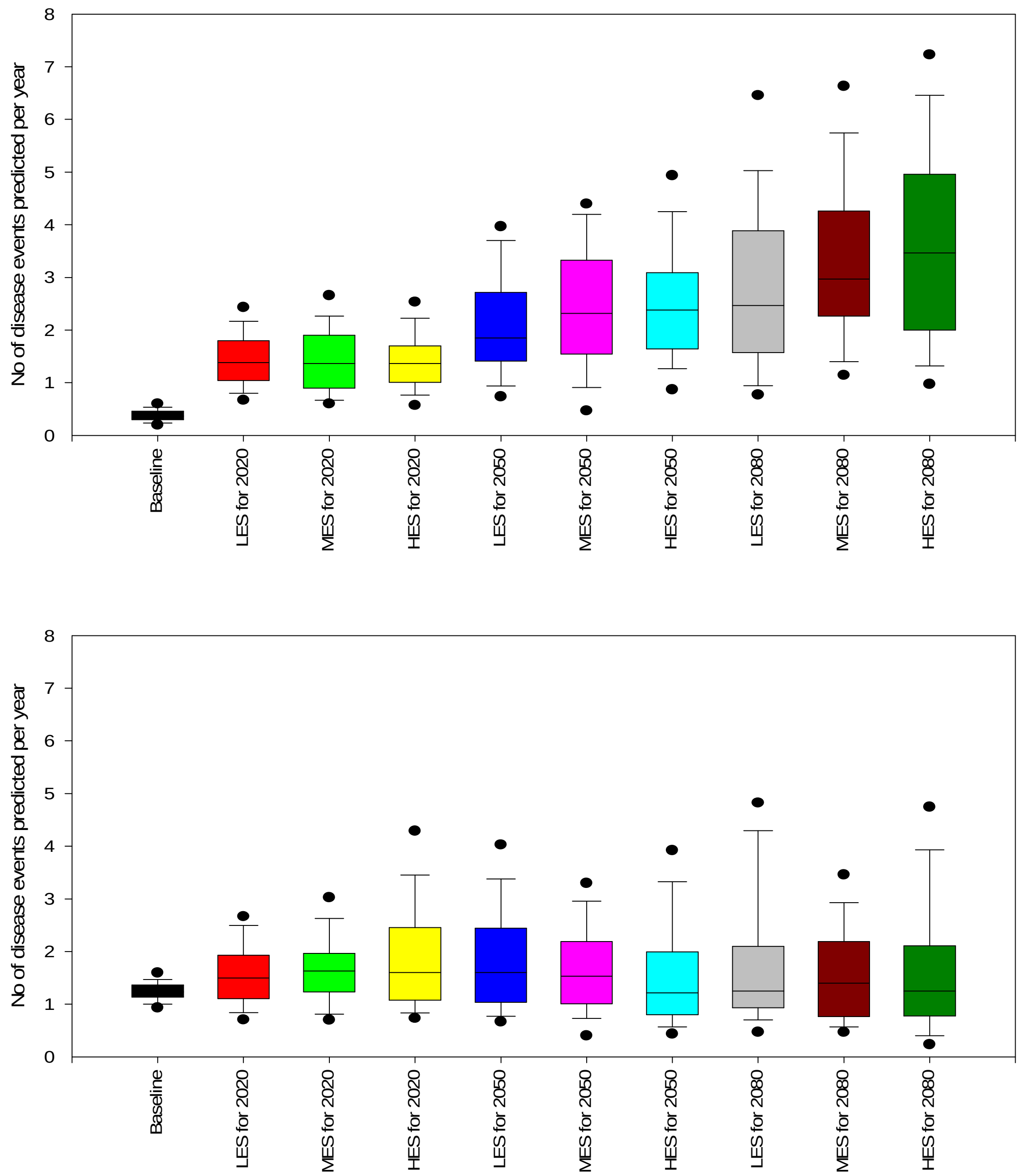


Figure 5-12 Box plots of the nine probabilistic projections at the various scenarios for two sites; Cupar, Fife (highest rate of increase) above and Geddington, Northamptonshire (lowest rate of increase) below. Each box-plot contains the mean number of potential events per year, summarised for the 100 runs for each scenario. The central mark in the box is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the 5th and 95th percentiles.

The increases in potential incidence of strawberry black spot in the north and west of Great Britain could gradually bring a shift in the distribution of the disease as regions where the disease was rare because of weather constraints become more suitable for the development of black spot epidemics (Figure 5-13).

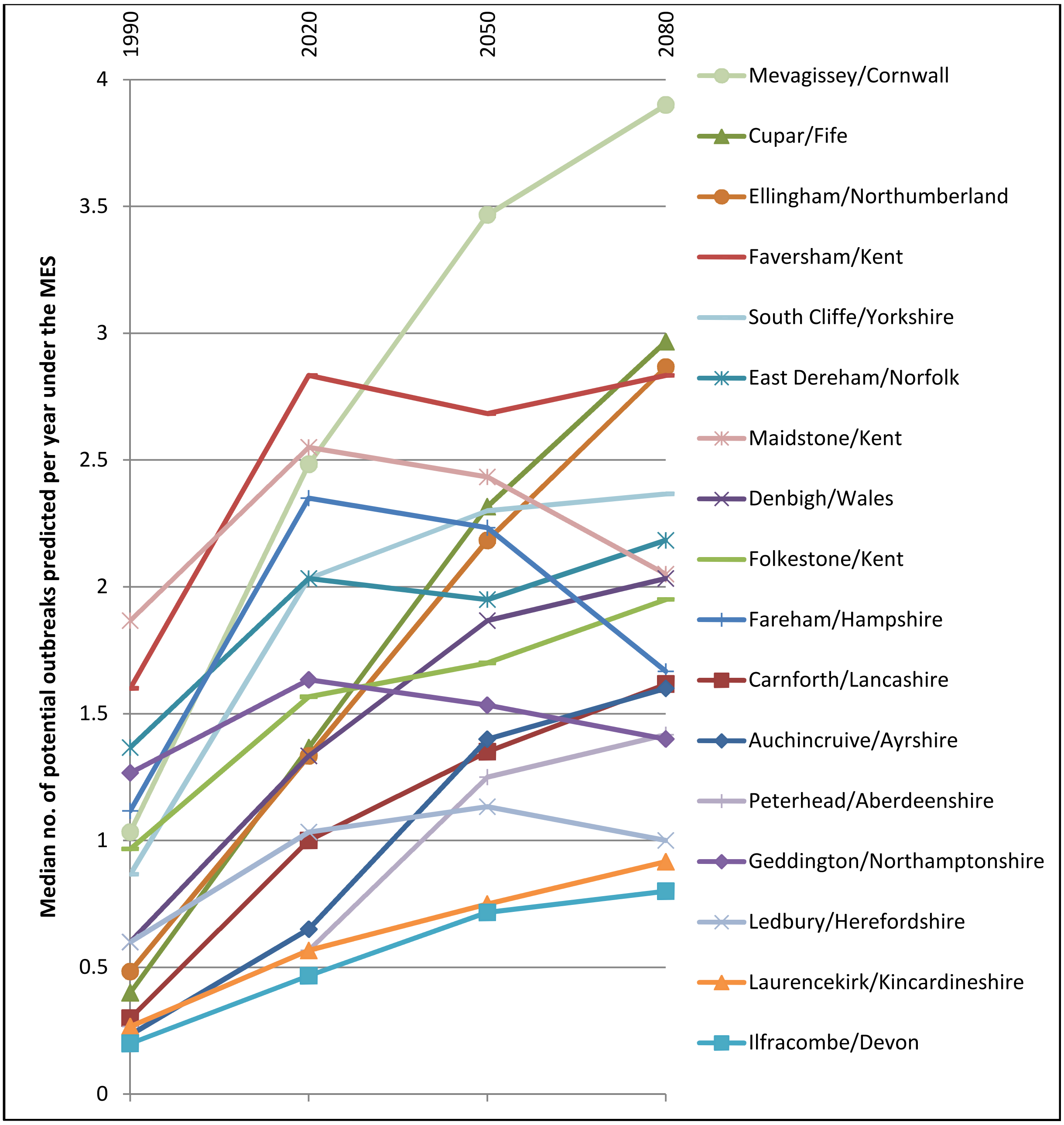


Figure 5-13 Scatter plot showing the predicted median number of potential outbreaks of strawberry black spot per year under the various timeframes under the A1B1 storyline (MES).

5.4. DISCUSSION

This study shows how a change in climate could potentially affect the incidence of plant diseases across Great Britain. Disease incidence was found to change both spatially and temporally depending on the particular changes in local weather patterns. The changes in incidence also varied according to the disease being studied, with black spot disease incidence increasing drastically, whilst grey mould increased only slightly in Scotland and decreased or remained the same in the rest of Great Britain. This variation in disease behaviour across Great Britain has been observed by others in climate change studies on *Cylindrocladium quinqueseptatum* leaf blight on eucalypts in mainland South East Asia (Booth *et al.*, 2000) and in phoma stem canker in the UK (Evans *et al.*, 2008, Stonard *et al.*, 2010, Butterworth *et al.*, 2010). This is expected since disease epidemiology is highly dependent on climate. Moreover, weather variables such as temperature, humidity and rain are important factors affecting the development and growth of fungal diseases (Rosenzweig *et al.*, 2001, Stonard *et al.*, 2010) and are very useful as predictors in building models for fungal diseases, if the conditions for infection are previously known.

Another outcome of this study was the increased variability in potential disease incidence between climate projection runs. This was found to be the case for all three diseases in all of the probabilistic projections. This variability originates from the output of the UKCP09 climate projections (Murphy *et al.*, 2009) and, whilst providing an added level of complexity that can hinder forward planning in disease management (Turner, 2008, Garrett *et al.*, 2006), knowledge of this variability is essential in enabling the farming sector to adapt to the challenges this might bring.

The change in plant disease incidence brought about by climate change, can influence the structure and geography of agriculture, and in particular the strawberry sector in the future. Changes in disease incidence and movement of disease to areas where it was previously not a problem can lead to substantive regional impacts unless the sector can adapt itself to these changes. Moreover, impacts of climatic change on the crop physiology, could affect the interaction between pathogen and host, and potentially also induce changes in the pathogen's epidemiology (Garrett *et al.*, 2006).

Disease prediction tools can be instrumental in shaping adaptation strategies to prepare the sector for these challenges. The versatility of the UKCP09 climate projections makes disease modelling much easier, since datasets can now be accessed easily following an initial registration and screening process. By combining these versatile climate projections with a disease model, practitioners can build scenarios of impacts such as those presented here. Moreover, if these are based on weather variables as the main predictors they can help the agricultural industry focus its efforts for adaptation by tackling the most urgent issues and diseases. Potential threats could be turned into opportunities by preparing the industry to adapt to those diseases that might become a problem in the future. In fact, early adaptation has often been seen to lead to economic gain notwithstanding climate change as suggested by Barnes *et al.* (2010), who claim that the predicted impacts can be cancelled and, in most cases even “improved upon”, with adaptation strategies. These adaptation strategies should take into consideration the increased variability and extremes in the projections, since these can potentially lead to the worst economic impacts on the agricultural sector. Plant breeding can focus on improving disease resistance and new plant protection products could be developed that are acceptable to EU law. Development of resistant varieties and novel crop protection products can take decades and it is in these areas that disease prediction can be most useful, since it provides an early warning system to plant breeders on what may become an issue in the future.

Notwithstanding the usefulness of the disease prediction models, used in this study they are simplistic in nature and assume that inocula are present throughout the territory being studied and the same production and disease management practices are used throughout. Moreover, these models only provide information on the potential frequency of outbreaks and do not include information on the potential timing of these outbreaks, which could be useful for management practises. They also depend on the appropriateness of the chosen conditions for infection, and might vary slightly if a different temperature range, precipitation or duration is chosen. They also focus on the nfection time and do not take into consideration the latent infection period. Under real conditions, infection and disease outbreaks are still known to occur for these diseases under higher or lower temperature, rain or humidity conditions than the ones chosen, though possibly at slower rates (King *et* *al.*, 1997, Maas, 1998, Leandro *et al.*, 2003, Blanco *et al.*, 2004). What these models attempt to determine however is not the change in actual disease incidence, but the change in the likelihood of the disease occurring by focussing only on the ideal conditions needed for their development. Nonetheless, one way to increase the accuracy of these models is to do a sensitivity analysis (see definition) on the selected conditions, by modifying them slightly with respect to temperature, rainfall and humidity and re-running the model variants and then testing for differences with the original choice of conditions. Thus whilst being indicative of potential changes in disease incidence in Great Britain for three diseases, more work needs to be done to build more detailed disease models that could give further information to policymakers and the industry.

In spite of this, in order to be most effective however, such models should be used in conjunction with social science methods to assess the impacts of climate change on agriculture. Farming has evolved over many thousands of years and diversified every time it was faced with challenges. The same will no doubt happen with climate change and farmers will adapt to survive. Disease forecasting studies could help bridge the gap between natural and social scientists working on climate impact studies by providing the latter with a tool to trigger responses in the farming community and enable dialogue on adaptation. The outcome could then be used by the policy makers to stimulate adaptation in the agricultural sector to climate change. This would enable a bottom-up approach, whereby solutions found by the farming community with the help of natural and social scientists working together, could be channelled up to policy makers to help British agriculture adapt to and survive climate change.

Chapter 6 Climate change and the strawberry industry

6.1. INTRODUCTION

There has been consensus over the last twenty years that there is a disparity in the impact of climate change on different geographical regions. The lower latitudes, including the tropics, are expected to be worst affected by climate change. This notwithstanding, temperature change in the lower latitudes is smaller when compared to the global change in temperature (Rosenzweig and Parry, 1994). Any warming above the current temperatures is expected to decrease crop yields in these regions (Parry *et al.*, 1990, Rosenzweig and Parry, 1994, Easterling and Apps, 2005, Salinger *et al.*, 2005).

The mid to higher latitudes, on the other hand, are expected to have increased crop yields in a climate change scenario (Parry *et al.*, 1990, Rosenzweig and Parry, 1994). The temperature changes, particularly in the higher latitudes, are estimated to be comparatively higher than those occurring on a global scale (Parry *et al.*, 1990). This would lead to more favourable temperatures for crop production in the northern crop areas and will result in a longer growing season and an expansion of the suitable area for crop production (Salinger *et al.*, 2005). This positive trend is expected to happen with an increase of 1-3^{o}C, with some regional variation. At larger amounts of projected warming, most temperate crop yield responses become generally negative (Gitay *et al.*, 2001, Stern, 2007, IPCC, 2007b). At higher temperatures, greater evapotranspiration appears to overcome the benefits of warming and increased precipitation (Easterling and Apps, 2005).

The UK is one of those countries expected to benefit from climate change in a number of ways: increased productivity due to warmer temperatures, less frost damage, crops shifting northwards and the introduction of new crops. Changes in climate are likely to shift thermal limits of agriculture in the order of 300 kilometres of latitude and 200 metres of altitude per 1^{o}C (Hulme *et al.*, 1993). Moreover, since several crop species such as wheat, maize and sunflower have their contemporary northern limits in the UK, an increase in temperature would, *ceteris paribus*, lead to a northward shift of cropping zones (Hulme *et al.*, 1993). On a practical level, an increase in temperature and decrease in rainfall would also increase the number of machinery work days, thus improving the workability of the fields (Brignall *et al.*, 1994).

New crops currently not grown in the UK, or grown only in isolated pockets, are also expected to become more widespread. With warming of 1.5^{o}C, much of lowland England and Wales would be suitable for growing navy beans (Holloway *et al.*, 1995). Viticulture is also expected to become more widespread with a warmer climate (Spellman and Field, 2002). It is currently on the northern limit for economic production in the UK (in some isolated pockets in the south), and could extend into Scotland with the predicted climate change scenarios. Bisgrove and Hadley (2002) add that in gardens the grape might eventually replace such fruits as raspberry and blackcurrant which will not respond as well to increasing temperatures.

On a physiological level, climate warming in the UK could have clear-cut benefits such as reduced incidence of frost, particularly in the south, where frost becomes increasingly rare and frost caused damage on precocious growth accordingly decreases. On the other hand, plants having long chilling requirements might have growth delayed in spring due to warmer winter temperatures. In blackcurrant, raspberry, apple and other fruits, the plant needs a cold period to form flower buds. Insufficient chilling would result in delay, abnormality or failure of flowers (Bisgrove and Hadley, 2002). Moreover, the faster growth and development in winter does not always lead to a higher yield at the end of the crop season. Increased speed of development may mean that the plant is unable to use the full length of the growing season before it dies. Plants like carrot, which are harvested early in their development, will increase in yield. On the other hand, plants harvested at the end of their natural growing season, like broccoli, cauliflower and onion, may produce lower yields as the accelerating effect of temperature hastens crop maturity (Bisgrove and Hadley, 2002).

These changes in climate and potentially in crop physiology, will inevitably affect plant disease and the interaction between the crops and their pathogens. Impacts will be complex, and will vary depending on the pathogen involved, on the crop (Luck *et al.*, 2011), the interaction between the two, and also on the geographical location (Butterworth *et al.*, 2010). Knowing what these impacts might be could have an influence on improving food security through changes in disease management practices that would enable adaptation and thus minimize impacts on crop production and yield loss (Chakraborty and Newton, 2011). In view of this, the disease forecast models discussed in chapter 5 will be used in combination with the social science study described in Chapter 4, to assess the potential impacts of climate change on the British strawberry industry. A number of themes will be studied including regional impacts on the strawberry sector, the impacts on plant disease and how this will affect the sector, what all this would mean to the strawberry industry in the UK and elsewhere, the sector's vulnerability and how it could adapt. The conclusions taken from this chapter could throw light on future potential change in the strawberry industry with climate change, and more importantly, contribute towards achieving the final objective mentioned in the Introduction to this thesis.

The rest of this chapter is divided into three major sections. This introduction is first followed by a continuation of the literature review and a description of the methodology used to collect the data and assess it. This is then followed by a results section, and a separate discussion.

6.1.1 Temporal shifts

The increase in temperatures brought about by climatic change, could lead to a shift in the growing season, leading potentially to a general increase of more than 20% in the growing period, particularly in the high latitude regions all around the world (Leemans and Solomon, 1993, Porter and Semenov, 2005). In many places, the growing period will even begin more than a month early. The tropics, on the other hand, will only see a slight shift in the growing season (Leemans and Solomon, 1993). Evidence of this seasonal shift is already available by studying the Spring Index first bloom dates, which is roughly when dominant trees show budburst in deciduous forest biomes. Most areas are getting earlier dates, at an overall average rate of approximately -1.0 days decade^{-1} across most temperate Northern Hemisphere land regions over the 1955–2002 period (Schwartz *et al.*, 2006). Certain critical temperature effects which have an influence on plant growth are also changing. The length of the period spent with no average daily temperatures below 5^{o}C is also increasing in most regions at an average rate of 1.6 days decade^{-1}, whilst the spring last freeze dates are getting earlier on average at a rate of -1.5 days decade^{-1} (Schwartz *et al.*, 2006).

In the Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, it was estimated to a high confidence level that these higher minimum temperatures will be beneficial to some crops, especially in temperate regions, whilst being detrimental to other crops, particularly in low latitudes. On the other hand, higher maximum temperatures would be generally detrimental to numerous crops (Gitay *et al.*, 2001).

6.1.2 Extreme events

Whilst the climate is warming, the incidence of inter-annual climate variability accompanying mean climate changes (also known as extreme events) is actually increasing. Although being of particular concern in the past, it has been recently widely accepted by the IPCC that increases in the frequency of climate extremes may lower crop yields beyond the impacts of mean climate change (Easterling and Apps, 2005, Easterling *et al.*, 2007). This increase in extreme events could have the greatest impact on developing countries where a greater proportion of the population relies on agriculture. In these countries, extreme events could lead to food shortages and increases in food prices, potentially leading to widespread starvation. Such events could increase poverty vulnerability in many developing nations (Ahmed *et al.*, 2009), whilst having little impact in the developed countries which have widespread adaptation techniques. In fact a study of the impact of extreme events on UK agriculture in the last 50 years has suggested that the damage to crops over time has decreased to the point where extreme events are now having a minimal impact on the overall national production due to a better adapted agricultural sector (Wreford and Adger, 2010). In fact wealth generation and socio-economic development have been shown to offset exposure and vulnerability of the farming sector to climate extremes (Patt *et al.*, 2010).

6.1.3 Climate change and adaptation

It now widely accepted that in the coming decades adaptation options and adjustment processes are necessary if the private sector and governmental entities are to make climate-sensitive sectors more resilient to climate variability, and to limit damage from - or take advantage of - potential long-term changes in climate. This is particularly so for agriculture, being one of the most sensitive sectors to climate change.

Although farmers already tend to employ measures that enable them to limit their losses from climatic change, these often tend to come slowly after losses have already started occurring. These sometimes need to be accompanied by changes in government policy, both on a national and international scale, to enable flexibility and offset damages. The benefits of adaptation vary with crops and across regions and temperature changes; however, on average, they provide approximately a 10% yield benefit when compared with yields when no adaptation is used (Easterling *et al.*, 2007). Adaptation options could include changes in crops and crop varieties, development of new crop varieties, changes in planting schedules and tillage practices, introduction of new biotechnologies, and improved water-management and irrigation systems, which have high capital costs and are limited by the availability of water resources (IPCC, 1997).

Rosenzweig and Parry studied the effect of two levels of adaptation on offsetting climate change scenario losses of crops and incidence of risk of hunger (1994). The small scale adaptation included shifting the planting date (±1 month), increasing the application of irrigation water and changing the crop variety. On the other hand, the large scale adaptation measures included large shifts in planting date (>1 month), increased fertilizer application, installation of irrigation systems and the development of new varieties including genetic manipulation. Whereas with no adaptation they predicted a drop in global crop yields of 1-9%, with small scale adaptation they obtained a decrease in global crop yield by 0-5%; with large scale adaptation, it ranged between an increase in yield of +1% to a slight decrease of -2.5%. However, when considering the effect of change on prices, these increased from 25-145% with no adaptation, 10-100% with small scale adaptation, and -5 to +36% with large scale adaptation. Adaptation also affected the number of people at risk of hunger. These varied from 10-60% with no adaptation, 6-50% with small scale adaptation, and -2 to +20% with large scale adaptation (Rosenzweig and Parry, 1994). In another review, Easterling and Apps (2005) found that with adaptation the mean returns can change by −11 to + 6% relative to the base climate, whereas without adaptation mean returns change by −8 to −31%.

6.1.3.1. Adaptation techniques

Adaptation techniques in agriculture can be quite varied, depending on the geographical region, farming community and farmer's wealth. One of the main methods of adaptation is through a change in the crop variety. In northern latitudes, where a warmer climate will lengthen the growing season, adoption of later-maturing, higher yielding cultivars to increase crop yields would be a recommended adaptation strategy since soil moisture here is adequate and the risk of heat stress is low (Parry *et al.*, 1990, Kaiser *et al.*, 1993, Salinger *et al.*, 2005). On the other hand, temperate crops may be genetically more restricted in the range of acceptable growing conditions than are varieties with more equatorial distributions, thus reducing their adaptability to new conditions (Leemans and Solomon, 1993). In lower latitudes, where growing season length is reduced by high temperatures, a shift to shorter season and more heat tolerant species is preferred (Parry *et al.*, 1990). In drier areas, a shift to early-maturing drought tolerant varieties will provide a measure to avoid or reduce summer heat and water stress by using crops having an increased resistance to heat shock and drought (Salinger *et al.*, 2005).

When changing variety is not enough, the use of technologies to 'harvest' water, conserve soil moisture (e.g., crop residue retention) and use water more effectively could become more widespread. In cases of increased rainfall and flood risk, changes in land management could help avoid erosion, prevent waterlogging and nutrient leaching (Easterling *et al.*, 2007).

Diversifying income by integrating other farming activities such as livestock raising could also maximise income, thus ensuring the economic sustainability of the farm. On the other hand, when costs outweigh the economic benefits such that farmers cannot sustain a living, it might be advisable to shift farmers engaged in agriculture in these marginal locations to non-agricultural income opportunities, or entice them towards other more productive farming locations, or more productive activities (Mendelsohn *et al.*, 2007).

Adaptation should also be driven by policy change, both at a national and international scale. Financial incentives and favourable trade agreement could either help mitigate some of the economic burden faced by the farmers or push start change in agricultural trends towards more climate change adapted crops. Some measures, however, may face political or cultural opposition that can limit the extent of their utility. GMOs are one case in point. Although they could offer solutions to developing crop strains capable of coping with a broader range of environmental conditions, public mistrust is still widespread and legislation exists in Europe that limits their use.

The benefit of adaptation tends to increase with the degree of climate change only up to a certain point. Adaptive capacity is exceeded with a temperature increase of more than 3°C in low latitudes and 5^{o}C in temperate regions. Changes in policies and institutions will be needed to facilitate adaptation to climate change. In the contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change in 2007, the concern was raised that pressure to cultivate marginal land or to adopt unsustainable cultivation practices as yields drop may increase land degradation and resource use, and endanger biodiversity of both wild and domestic species. The report also recommended that adaptation measures must be integrated with development strategies and programmes, country programmes and Poverty Reduction Strategies (Easterling *et al.*, 2007).

6.1.4 Research design and methodology

In view of the topics discussed in this chapter so far, the social science study described in Chapter 4 was used to collect data from strawberry growers and the industry on climate change to address some of these issues. More specifically in the semi-structured interviews, the respondents were shown the probabilistic projections of potential disease incidence described in Chapter 5, to stimulate their responses on how these changes could potentially impact them and how they could adapt to any impacts. A full description of the methodology used and data analysis is given in

Chapter 4, section 4.2. Data generated from the postal questionnaire and case study interviews gave rise to the development of a number of themes related to climate change, which for the sake of simplicity are being analysed and discussed here as a separate chapter.

6.2. RESULTS

The results section is divided into three broad themes. The first part "examining the impacts", assesses the threats that may affect the sector from climate change, and how the sector will respond to these. The second part titled "Climate change and plant disease", examines the vulnerability and adaptive capacity of the strawberry sector to the potential impacts of climate change on plant disease. The third part titled "Opportunities from climate change" examines the responses of growers to how the sector and individual business may find opportunities from climate change.

6.2.1 Examining the potential impacts

Just over half (54.7%) of all the participants in the study[23] believe that climate change will have an impact on their business (Table 6-1) whereas around 30% believe it will not affect them. When the participants were divided into various categories depending on the production system used, size of enterprise, geographic location and age group, it emerged that the farms involved in ground production systems believe most that climate change will have an impact on them, whilst the mixed production system farms feel least affected by climate change. Older growers were the least well informed about climate change, whilst the younger growers and the respondents from the supply chain were the least decisive[24] about the impacts. Geographically, there was very little difference between responses from the two regions i.e. Kent and Scotland.

There was very little difference in the proportions of overall respondents believing that climate change will have a negative or positive impact on their business (Table 6-2). This was so because some respondents believed that climate change might have as many negative as positive impacts on their business. On considering the individual categories, the supply chain was the most positive about how climate change will affect them with 83% of respondents believing that it will have a positive impact on their business. With respect to farm size, small enterprises were more negative about impacts when compared to large enterprises, which in turn were more positive about the potential impacts on their businesses.

[23] includes data from both questionnaire and interviews
[24] This represents those respondents that replied maybe, when presented with the question "Will climate change will have an impact on your business."

Table 6-1 Respondents' beliefs on ***WHETHER predicted climate change will impact them****. The values given are the proportion of respondents replying in that manner. The categories on the left represent various factions within the industry. Data for Overall, Small & Large enterprises, Ground, Substrate & Mixed production were taken by combining the questionnaire and interview data[25]. The rest were taken from the interview respondents only.*

Categories		Yes	No	Don't know	Maybe
Overall		55	30	3	12
Supply chain		50	20	0	30
Farm size	Small enterprises	53	39	5	3
	Large enterprises	58	24	3	16
Production system	Ground	70	18	3	9
	Substrate	62	38	0	0
	Mixed production	46	43	4	7
Geographic location	Kent	55	25	5	15
	Scotland	52	19	10	19
Age of respondent	Age under 40	43	29	0	29
	40 - 50	50	25	5	20
	50 - 60	61	17	0	22
	Over 60	43	29	29	0

With respect to production system (Table 6-2), mixed production growers were more positive whilst ground production growers were more negative. Both Scotland and Kent foresaw as many positive as negative impacts, although the responses were more extreme in Scotland with around 70% believing that climate change will have a positive impact there, whilst also having high negative impacts (63%). With respect to age groups, the younger respondents (under 50 years old) were more positive about climate change, whilst those over the age of 50 were more pessimistic about the impacts[26].

[25] Since some of the themes emerged from both the questionnaire and interview, care was taken to avoid double counting growers that replied to both, thus avoiding getting the same answer from the questionnaire and interview.
[26] This included both growers and respondents from the supply chain

Table 6-2 Respondents' beliefs on ***HOW predicted climate*** *change* ***will impact them****. The values given are the proportion of respondents replying in that manner. The categories on the left represent various factions within the industry. All data were taken from the Interview respondents only.*

Categories		Positive	Negative	Don't know
Overall		56	50	17
Supply chain		83	33	0
Farm size	Small enterprises	31	69	23
	Large enterprises	65	41	18
Production system	Ground	40	67	20
	Substrate	40	40	20
	Mixed production	70	40	20
Region	Kent	42	42	32
	Scotland	69	63	0
Age of respondent	under 40	67	50	17
	40 - 50	79	29	14
	50 - 60	36	73	18
	Over 60	20	60	20

6.2.1.1. Types of impact

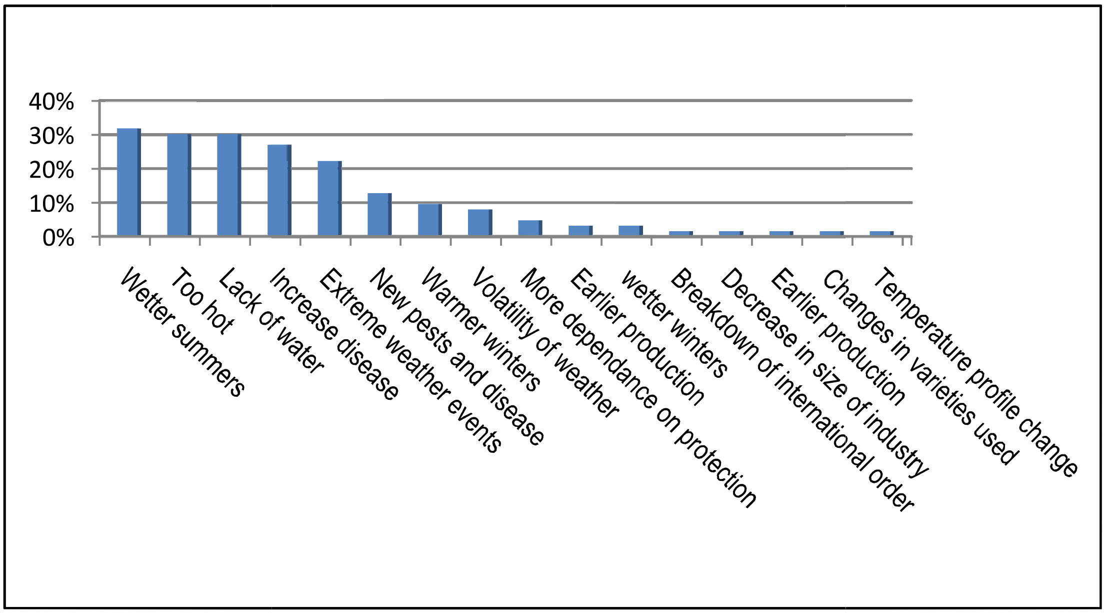


Figure 6-1 The threats perceived by respondents (questionnaire & interviews).

At first glance (Figure 6-1), the threats that the respondents were most concerned about, to which one third of the respondents replied to, were wetter summers, hotter summers and a reduction in water availability. An increase in disease incidence and more extreme events were also mentioned by a quarter of the respondents.

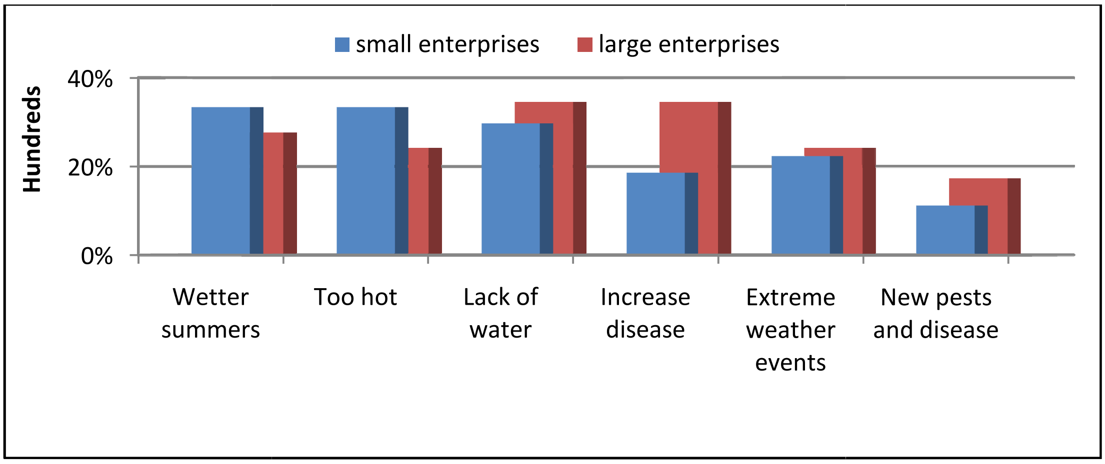


Figure 6-2 The six most important threats perceived by respondents.

The threats that were mentioned by at least 10% of the respondents were analysed in more detail by dividing them into various categories. Small enterprises were more concerned with excessive heat, whist large enterprises were more concerned with an increase in disease incidence (Figure 6-2).

Table 6-3 Proportion of responses to perceived threats by two categories of respondent: production systems and geographic region

Perceived threats from climate change	Production system			Geographic region	
	ground	substrate	mixed	Kent	Scotland
Too wet	41	6	35	18	82
Too dry	25	17	50	75	25
Hot summers	44	0	22	56	33
Warmer winters	60	0	40	60	40
Stronger winds	40	40	0	80	0
Pests and Disease	43	0	43	57	43

Growers using substrate production considered themselves to be the least susceptible to these perceived threats (Table 6-3), particularly with regards to pests and disease, hot summers and warmer winters. In contrast, growers using ground cultivation were perceived to be slightly more vulnerable to these threats, except for drought. The most obvious differences in responses were geographic. Respondents in Scotland were mostly concerned with too much rain, whilst respondents in Kent worried about everything else, except for too much rain.

6.2.1.2. How threats will bring change and adaptation in the industry

Eight threats were investigated in further detail by collecting information from all the participants in the case study interviews (Figure 6-3). Data on the growers' adaptive capacity were also collected. The data were then divided according to the various categories to investigate where the impacts would be most felt and how they could potentially affect the strawberry industry.

Different scenarios of climate change will bring threats that have varying impacts on the sector. Extreme events were considered to be the worst, with almost 90% of the respondents considering it as a threat. Other scenarios such as the introduction of new pests, poorer seasons and warmer winters were also seen as a threat by between 60-80% of the industry. Two other scenarios, such as weather being too hot and lack of water, were considered as being a threat by the same number of respondents that thought it was not a threat. Finally, two scenarios - change in demand and earlier springs - were considered as an opportunity rather than a threat.

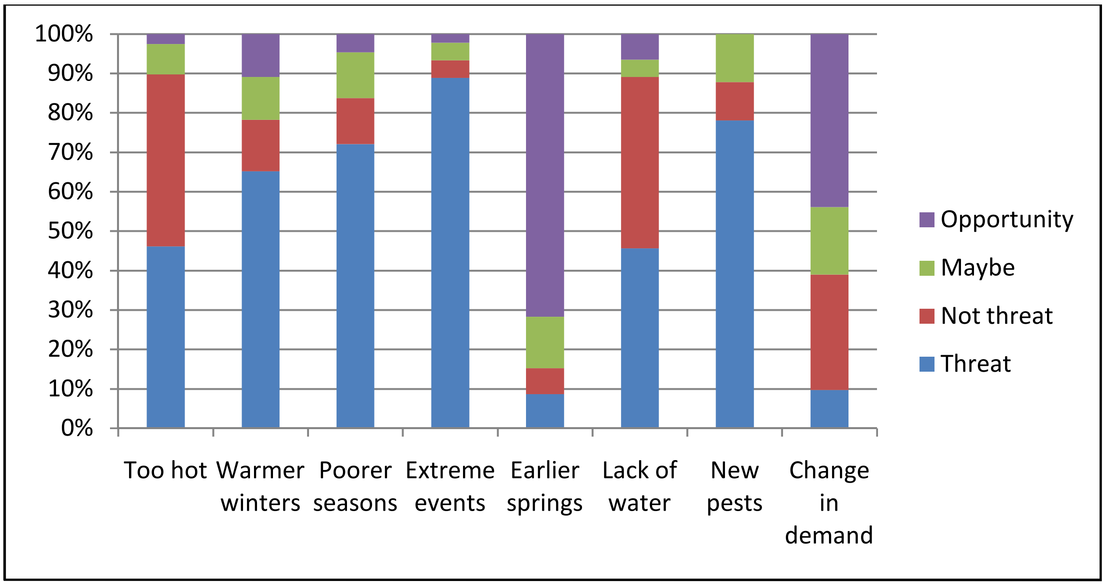


Figure 6-3 100% stacked chart showing how various climate change scenarios were considered as being threats, non-threats, or opportunities by the strawberry industry. Maybe represents the response of those that were undecided.

6.2.1.2.1. Extreme events

This was the scenario that most growers were concerned with (Figure 6-4). Moreover, extreme events for growers came in two categories: extreme winds and extreme rain. Damage from extreme rain events did not only affect open field growers, but also those enterprises that used extensive protection. In the latter, runoff from heavy rain off the tunnels would lead to subsequent flooding, impacting the ability of the growers to reach the land. As one grower from Scotland said:

"Yes we've had that with torrential rain, and it's been impossible to work and even transport the fruit from the field." SG15

For enterprises in more densely populated areas, such as in Kent, this was an even greater concern since poor drainage systems would often result in the growers flooding their neighbours, and this led to eventual problems with councils and further planning restrictions on polytunnels:

"We'd have to plan our drainage better because if we consistently flood our neighbours, that will get planning problems. Tabletops are less of an issue because it's falling onto grass." KG1

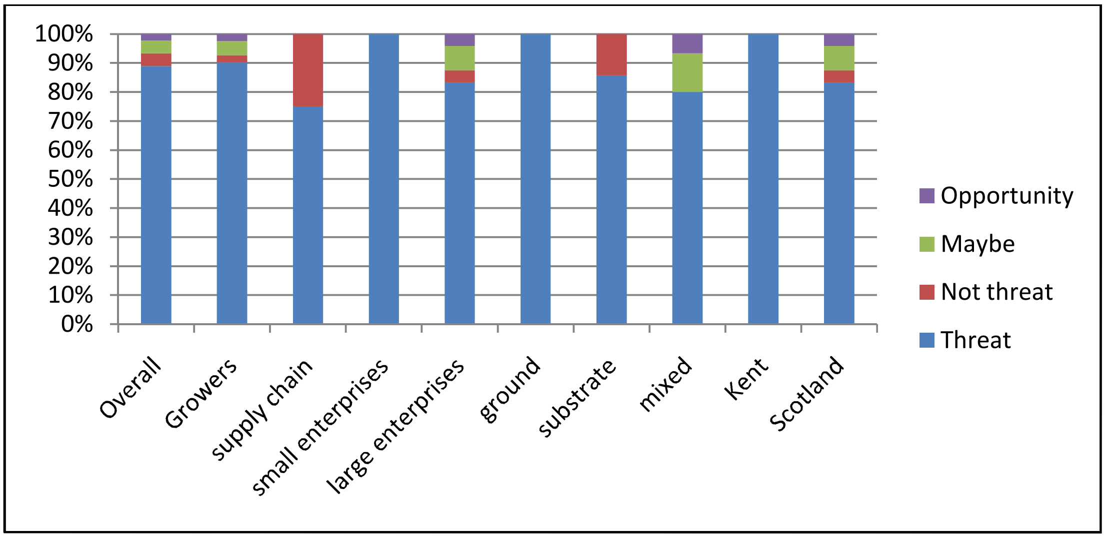


Figure 6-4 How different categories of growers or businesses within the industry see extreme events as a potential threat of climate change.

Growers in Kent, small enterprises and producers of ground cultivation methods were the most concerned about extreme events. When compared to other scenarios, the adaptation measures for these involved more capital investment in land modification or structures used for tunnels (Figure 6-5). The most common adaptation method was to change the tunnel design and strengthen their structure. A third of small enterprises also suggested going out of open field production by introducing tunnels. Large enterprises did not mention adding tunnels, but suggested increasing drainage instead. Around 15% of all growers suggested site selection as an important adaptive measure, especially so in Scotland, whilst relatively more growers in Kent than in Scotland opted for windbreaks instead.

The supply chain was seen as being one of the biggest driving forces for adaptation. On adapting to extreme events, one supplier of polytunnels said:

"So we made our tunnels stronger so you would stand most wind conditions. These tunnels are not regarded as a permanent structure so if you have a 80 or 100mph wind it's not guaranteed to withstand it, but we have made moves over the last few years to make the tunnel construction stronger". SS1

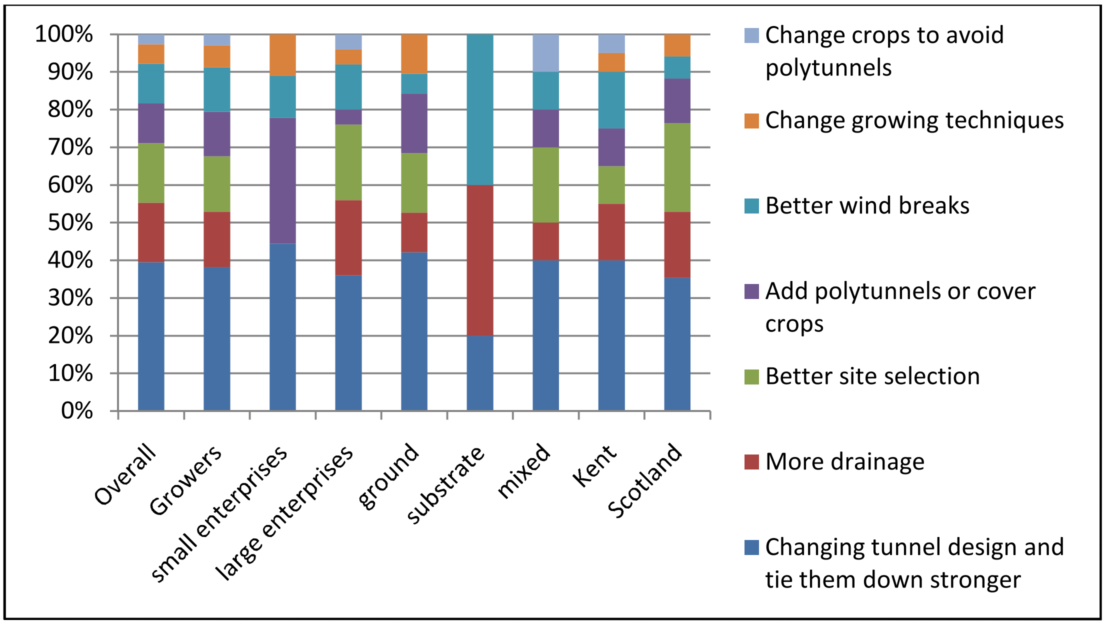


Figure 6-5 Adaptation measures proposed by different categories of businesses within the industry

Another supplier suggested how the cause of increased casualties from extreme wind damage is the nature of how the sector has changed in the last 15 years.

"... people are ready to test more and more the technology, some people keep the tunnels up all year round because they want to bed-make in winter and they [want to] force forwards certain varieties." OS1

The same supplier also suggested that climate change is driving some of the challenges for innovation and technological changes in the sector:

"So climate change is driving challenges for us. We had snow this winter. We are now developing the technology further. We got to a point where we can stand a 100km/hr winds if farmers buy the right kind of products from us. There seems to be more of it." OS1

6.2.1.2.2. Hot summers and drought

Hot summers and drought are somewhat linked, and can put pressure on strawberry production. Both scenarios are seen as a threat by around 45% of the industry (Figure 6-6). Nevertheless, the same proportion of respondents did not see it as a threat. Both scenarios are seen as a greater threat on substrate production.

Excessively hot summers were seen to impact farms in three ways: firstly, by making conditions difficult for workers; secondly, by pushing temperature beyond the ideal conditions for strawberry production, thus resulting in the plants producing fruit of inferior quality; and thirdly, by forcing the strawberry plants into heat shock.

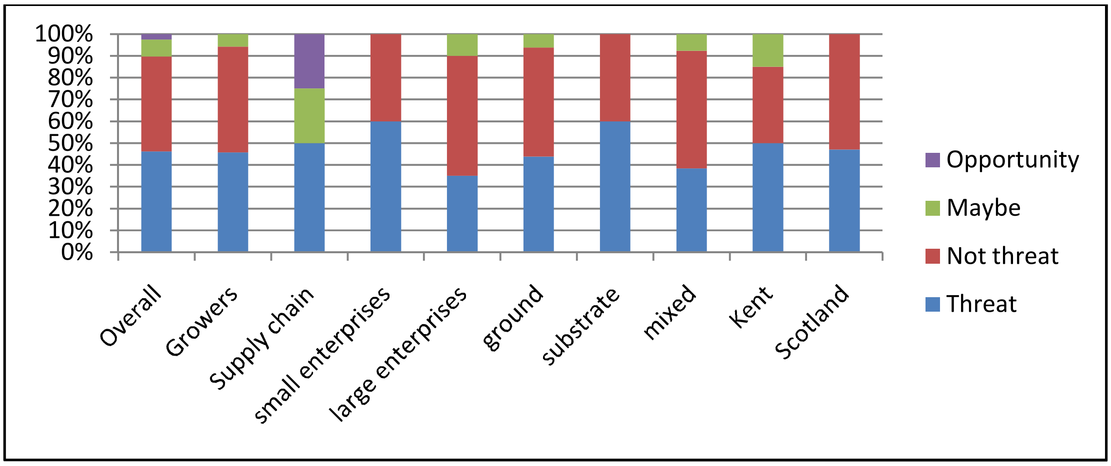


Figure 6-6 How different categories of growers or businesses within the industry see hot summers as a potential threat from climate change.

Drought on the other hand, forces growers to rely more on mains water and incur extra expenses. This was a greater problem in Kent, where almost 80% of the industry see it as a threat, compared to 20% of the Scottish strawberry industry (Figure 6-7). As one grower in Kent said, it could reduce the profitability of the business:

"We're on mains water here and it's getting really expensive. It's one of our main problems here. The water is there it's just that it costs so much money. It gets to a point when you cannot afford to use it anymore." KG15

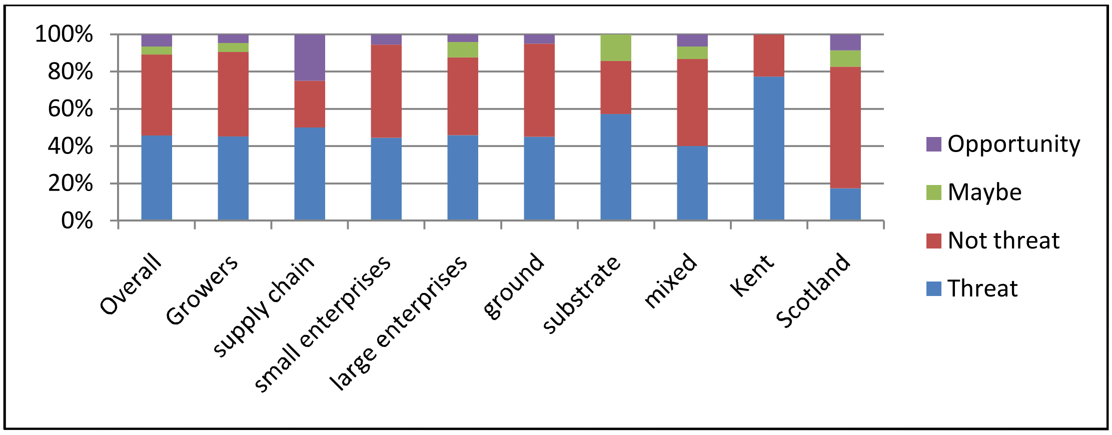


Figure 6-7 How different categories of growers or businesses within the industry see drought as a potential threat of climate change.

In cases of severe droughts, strawberry farms are usually forced to stop production by councils withdrawing their water extraction licence: " ... *that worries me for the price and if they start doing restrictions on us" (KG4)* and agriculture is seen as a low priority by the water authorities and it is one of the first sectors for which restrictions are set during a drought; *"It goes to the houses and industries first and to the farmers last." (KG9).* Most farm enterprises in Scotland did not have the same problem because they often had rivers running through them (as mentioned in their adaptations in Figure 6-9).

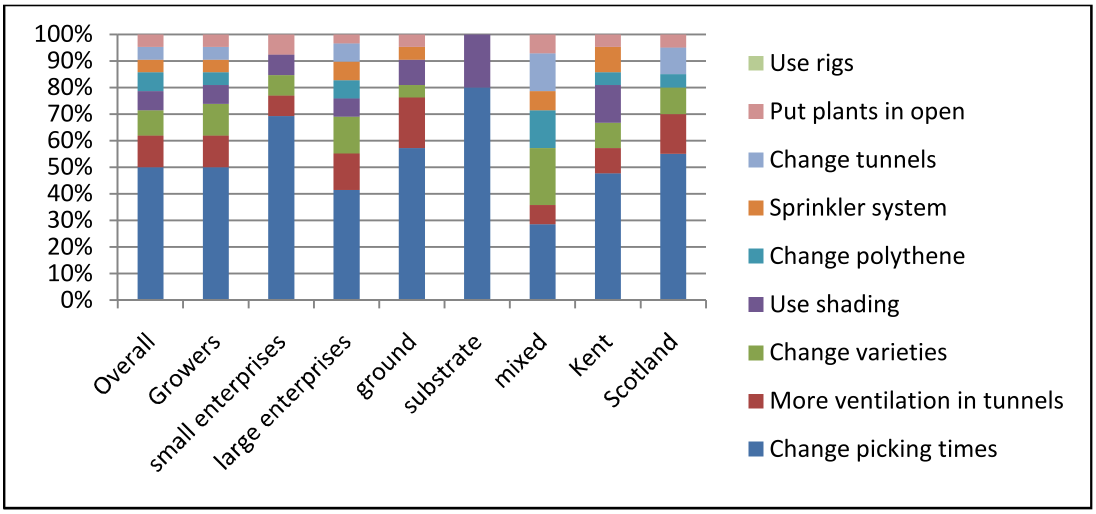


Figure 6-8 Adaptation measures to hot summers as proposed by different categories of businesses within the industry

The most common adaptation measure for dealing with hot summers (Figure 6-8) was a cultural change in behaviour, by changing picking times in order to avoid the hottest hours of the day. Picking would often occur between 4am and 11am and resume from 3pm till 9pm. More ventilation was another cultural method mentioned that would help control the temperature within the polytunnels.

The climate change scenario of warmer summers is another driving factor behind innovation and change in the sector. Once again, this is being driven by the supply chain that is attempting to meet the needs of the strawberry sector by developing technological innovations that enable the sector to maximize their gains. Supplier OS1 is one of the leaders of innovation in the industry and is currently funding 4 PhD studentships, one in the University of Lancaster in the UK and three at the University of Alexandria in Egypt. In the last five years, they have developed a product that reflects 70% of the IR reaching the tunnels. As the supplier said:

" ... the IR light is only associated with heat build up. It's not within the photosynthetically active region of the light spectrum. So by removing 70% of that IR, it keeps cooler tunnels." OS1

The polythene product was developed following research collaboration with the University of Reading and took only three years to put onto the market after the product was first developed by the University. A number of growers even mentioned using the product as an adaptation technique (Figure 6-8).

Another adaptation that derives from using innovative technology is the sprinkler system (Figure 6-8). This consists of an automated system of sprinklers located within polytunnels that turn on after the polytunnels reach a certain temperature (usually around 30^{o}C). The sprinklers spray a very fine mist into the air for 1 minute, at prearranged time intervals, until the temperature within the polytunnels starts falling again. This technique has been imported from the USA where it was originally developed.

The most common adaptation measure for dealing with a lack of water is the use of winter storage, which involves the collection of rain water in reservoirs or tanks. This was the most popular adaptation technique for growers in Kent (Figure 6-9), whilst extracting water from rivers running through their land was the most popular technique in Scotland. Some farm enterprises in Kent have already started installing reservoirs on their land, mostly by collecting water from their polytunnels through a guttering system similar to that used in houses. As one supplier said:

" ... we've looked at water balances on water usage, and if you collect the water in ... for a classic tunnel block ... we could be a net contributor to the water table. Assuming that sometimes the vents are up so you can't collect water, but we've modelled over the year that when the vents are down we can actually add to the water table rather than deplete it. But the technology is there, and it can be retrofitted to polytunnels." OS1

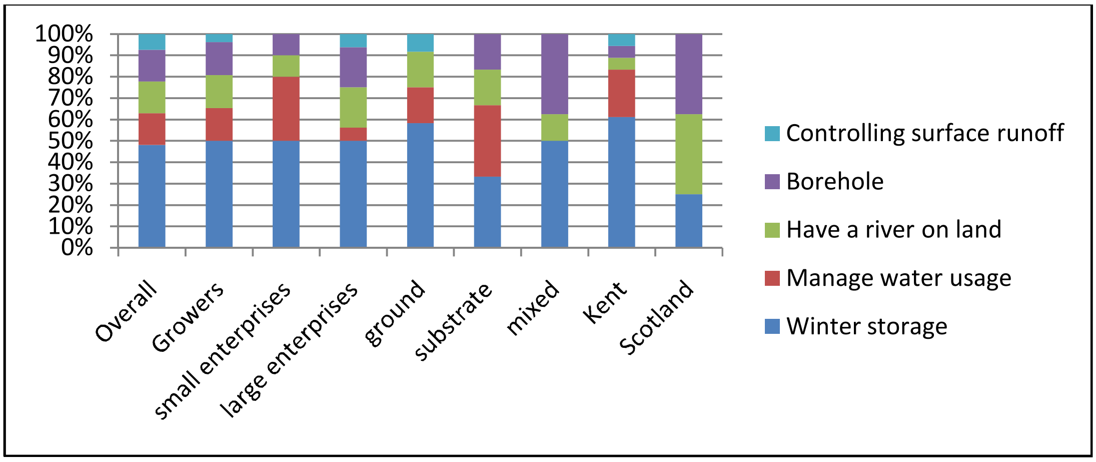


Figure 6-9 Adaptation measures to lack of water as proposed by different categories of businesses within the industry

Using different varieties is another method that is often mentioned by growers. According to an agronomist working with the industry (KS5), East Malling Research has been developing a cultivar that uses up to 90% less water compared to other cultivars.

6.2.1.2.3. *Warmer winters and earlier springs*

Warmer winters and earlier springs are two other climate change scenarios being predicted to have an impact on UK agriculture. Whilst both together are believed to be responsible for bringing the season forward, individually they may have different repercussions for agriculture. Warmer winters are more feared by the strawberry industry than earlier springs, which are actually considered an opportunity by most involved in the industry. Warmer winters are seen as being responsible for pest and disease carryover in the winter months, whilst they could also result in there not being enough winter chill to trigger dormancy in certain strawberry cultivars (Figure 6-10). As a small grower that grows crops in the open field said:

"I worry about winters, I need snow and frost. Snow and frost keep away disease and pests. You get a nice frost on that field for a week in December or January and I haven't half the problem of botrytis[27] in summer." SG16

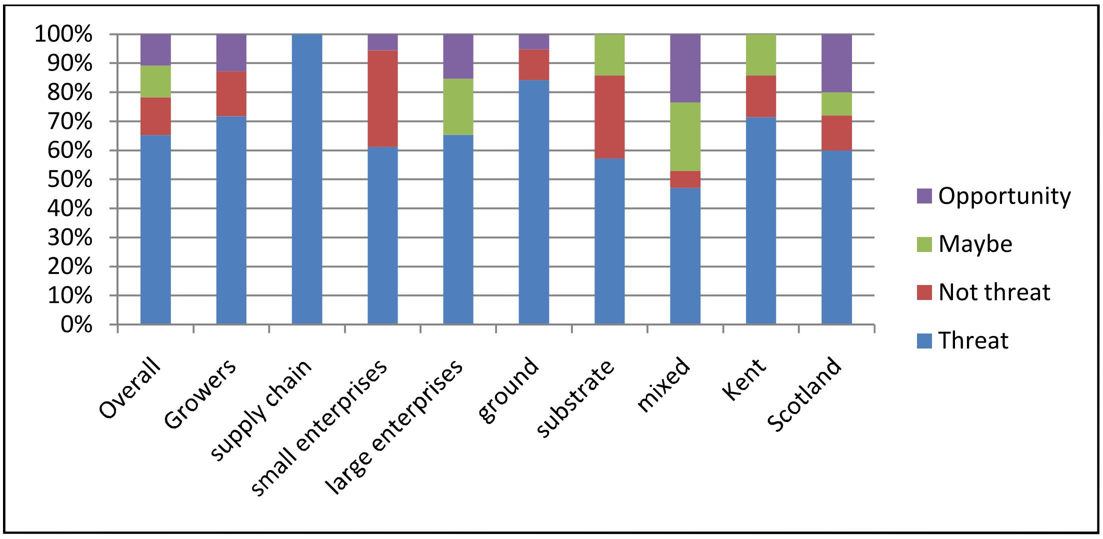


Figure 6-10 How different categories of growers or businesses within the industry see warmer winters as a potential threat from climate change.

Even the nurseries were concerned:

"Would become a problem for us because we'll struggle to find dormancy. Most of the UK growers' systems are based on using dormant plants. If you don't put a non-dormant plant in the chillers, it just rots. We've been waiting for some time to get some dormancy in the field now. As a general rule you need 500hrs below 5^{o}C." KS2

Warmer winters were seen as being more of a problem in Kent by about 10% compared to Scotland. Some growers in Scotland saw warmers winters up north as an opportunity. As one Scottish grower said:

"We've got a long way to go until it becomes a problem for us, so if it's a problem for others down south, it would be an advantage for us." SS4

Earlier springs was seen as an opportunity by over 70% of the industry (Figure 6-11). This was more so in the supply chain. The only threat foreseen by growers for this scenario was the increased threat of late frosts.

[27] When people within the strawberry sector refer to botrytis, they are referring to grey mould disease in strawberries caused by *Botrytis cinerea*.

"It's bad. The ground is not warm enough. Everything starts thinking its summer and they put blossoms up and you get a late frost." KG12

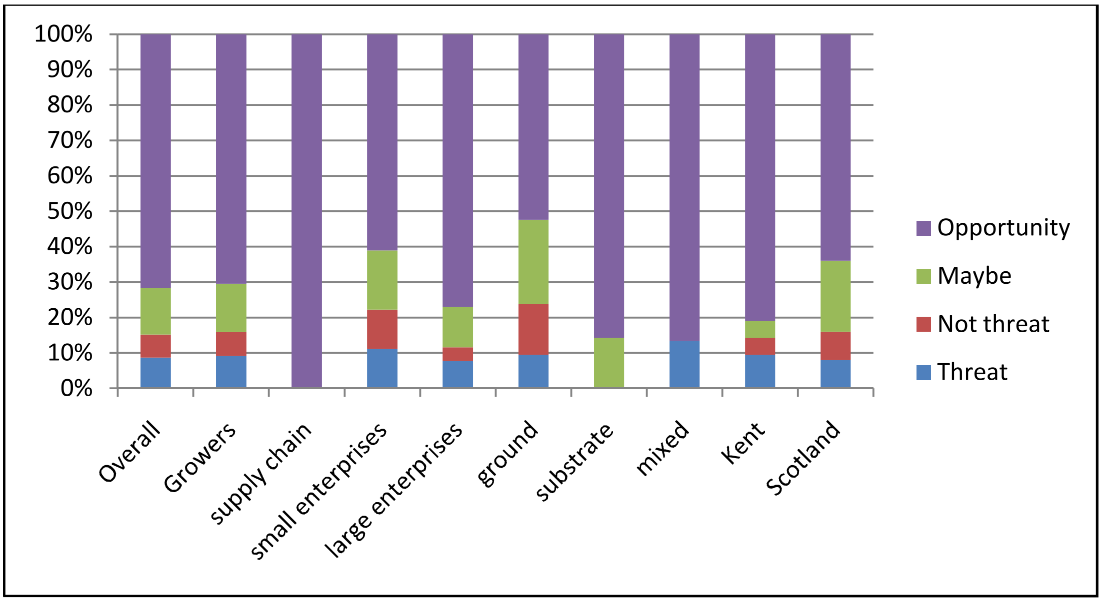


Figure 6-11 How different categories of growers or businesses within the industry see earlier springs as a potential threat from climate change.

One pick-your-own farm was slightly concerned that the crop might be too early before their clients are ready for the season:

"We had a blazing hot June this year which brought our strawberries earlier and our customers are not ready for that. Our production needs to fall in the school holidays. If it doesn't I have problems. I think I'm [going to] pack and leave. I'm glad you're telling us these things because they are really serious threats to the way we do business." SG17

The most popular adaptation measure for warmer winters is the use of different varieties (Figure 6-12), whilst the next most common method is to improve the spray programmes. The biggest contrast in adaptation measures was between small and large enterprises. None of the small enterprises suggested a change in the variety used, but two thirds focused on improving their spray programme. The difference in response of these two categories was in the nature of the threat. Small enterprises were predominantly concerned about the impact of warmer winters on pest and disease carryover, whereas many of the large enterprises were concerned about the lack of winter vernalisation on the plants. A similar pattern is followed between production systems, whereby only in the ground production system are spray programmes mentioned.

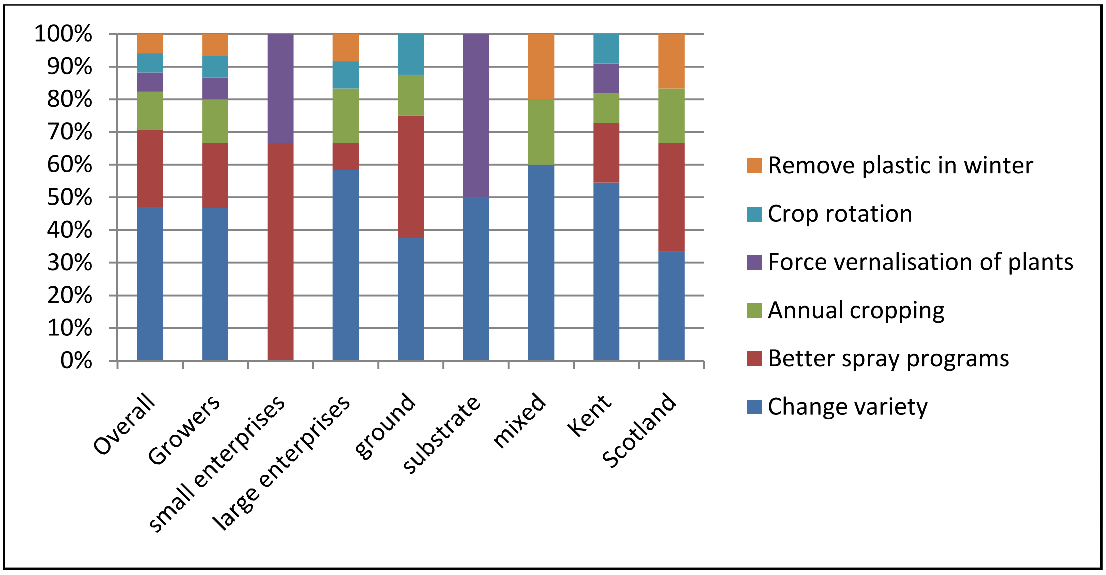


Figure 6-12 Adaptation measures to warmer winters as proposed by different categories of businesses within the industry

Since most respondents saw an opportunity in earlier springs, few of them actually recommended any adaptation measures. Of the ones that did, most suggested covering the plants either by using a fleece or else under tunnels (Figure 6-13). This was suggested as a means of protecting the crop from late frosts and snow.

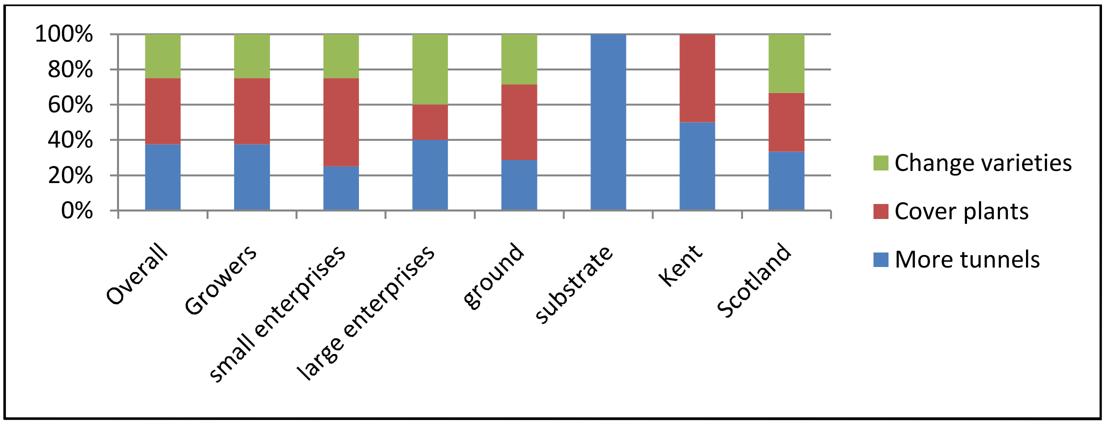


Figure 6-13 Adaptation measures to earlier springs as proposed by different categories of businesses within the industry

6.2.1.2.4. *Poorer growing seasons and a change in demand*

The scenario of poorer growing seasons (Figure 6-14) was suggested by many of the respondents as being a threat coming from climate change. This relates to the summers of 2007, 2008 & 2009, which were characterised by persistent rain, regular cloud cover and very few periods of sunny 'barbecue' weather.

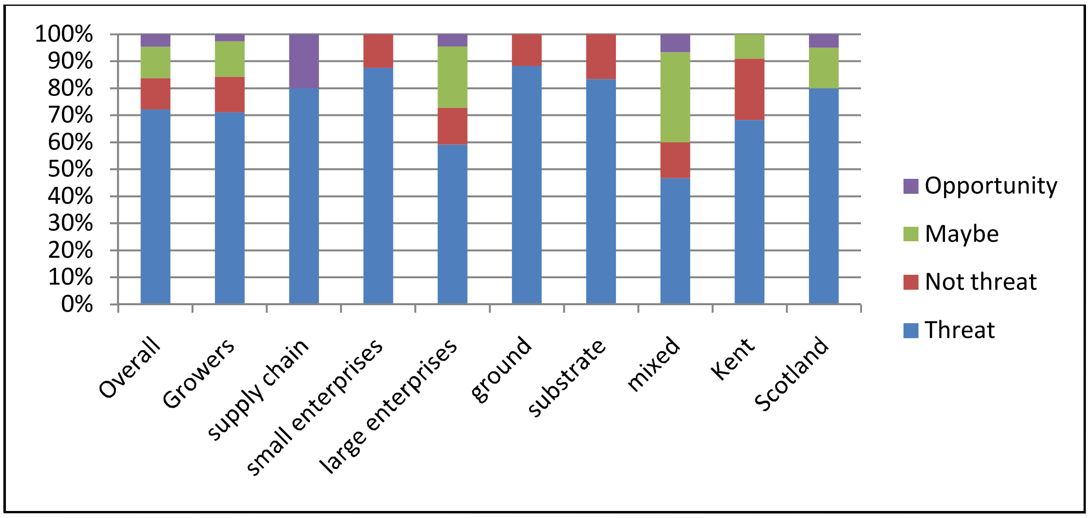


Figure 6-14 How different categories of growers or businesses within the industry see poorer growing seasons as a potential threat from climate change.

In some of the responses to the questionnaire, this weather pattern was suggested to influence a change in demand, with bad weather leading to fewer sales. However, the threat did not really materialise, with sales continuing to increase yearly to reach record sales in 2009, even with a poor summer season and a recession at hand. Nevertheless, over 70% of the industry suggested that poorer summers would be a threat. Small farm enterprises were seen to be more at risk from a poorer growing season, with over 85% of them seeing the scenario as a threat compared to fewer than 60% of the large farm enterprises which can rely on having polytunnels. As one large enterprise said:

"Well obviously the tunnels give one an advantage there. You can pick for longer times, you're not getting that much disease, so you spray less, and you're recovering more of your crop than if you left it outside. Last year we reckon we walked away from 10 acres of fruit [that was out in the open], that's sort of 50 tonnes of fruit at £2000/tonne, that's £100 grand of fruit. It was rain. Every time we went out there it rained so hard that it damaged the fruit." KG13

Users of ground and substrate systems were concerned at the same level, but for different reasons. For small farm enterprises using ground production, the main concern was the direct impact of rain on the crop, such as rain damage and also impact on disease:

"If it did happen it would be a problem. Especially if it would happen for a prolonged period in summer. That again would make us think if we keep doing the PYO, and whether to introduce polytunnels." KG16

For substrate systems and other covered systems, the main concern was the impact on light intensity, which would affect the yield, particularly in Scotland.

"Yes massively. Can't think of anything [worse]. If its wind or rain or frost there is something we can do but if its sunshine there's not much we can do." SG12

Mixed production systems were found to be less concerned, with not more than 50% of the farms in this category suggesting that it was a threat. With respect to geography, more growers in Scotland saw it as a threat, by around 12%.

Change in demand (Figure 6-15) brought about by a change in the weather was seen to be a threat by only 10% of the sampled population. Just under 30% of the industry said it was not a threat, and over 40% actually said it could be an opportunity. The latter group, nevertheless, believed this could be an opportunity if the weather in summer gets better and warmer in the longer run. Moreover, the respondents suggested that currently fruit and vegetable consumption in the UK is at less than 3 per day (as compared to the 5 per day being promoted by the NHS), so if it continues being promoted as a healthy option, consumption and demand should increase, irrespective of the weather. As one Scottish grower said: "Till now its 2.3 portions of fruit a day so we're not even reaching half." SG8

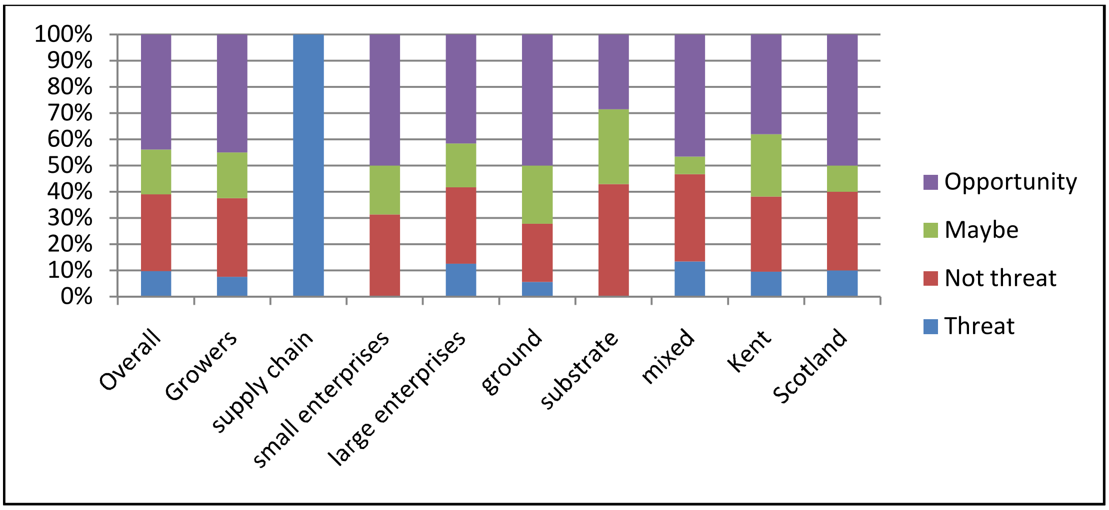


Figure 6-15 How different categories of growers or businesses within the industry perceive a change in demand as being a potential threat.

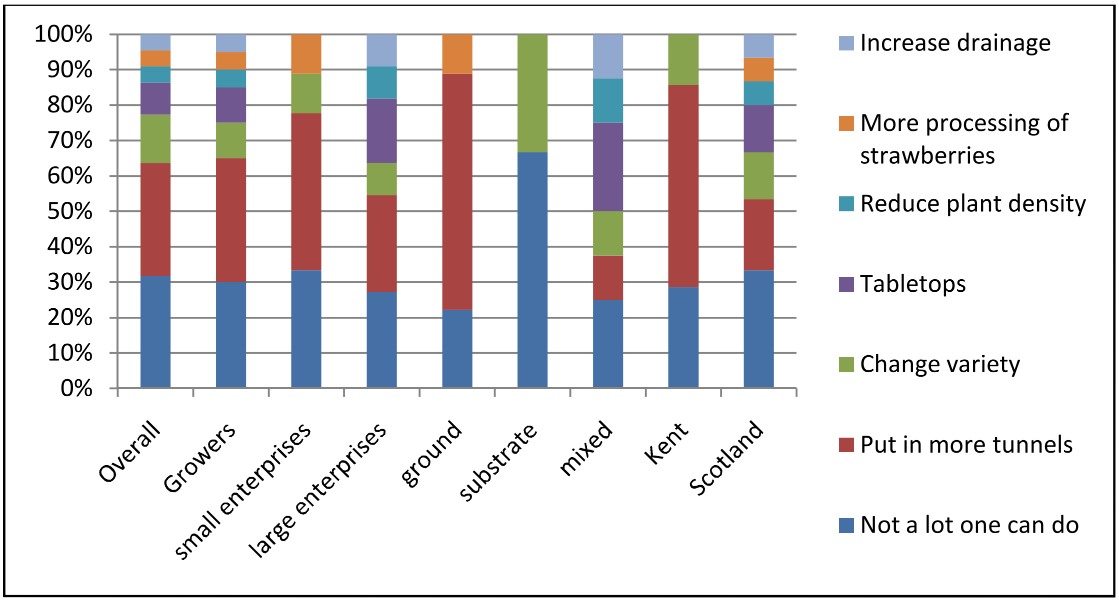


Figure 6-16 *Adaptation measures to poorer growing season as proposed by different categories of businesses within the industry*

On analysing the adaptive measures taken to respond to poorer growing seasons (Figure 6-16), just over 30% of the industry said that there was not much one could do to adapt. Of these respondents, 70% were based in Scotland and their main concern at that latitude was the impact of poor growing seasons on light intensity. As one respondent said:

"It's very hard to adapt [to] that. It's a real struggle. At the moment we just hope for good weather. We protect as much as we can, because we're a 100% protected [having all our crop under polytunnels]. ... if the light levels are low, they think we're going into autumn so the plants shut down too. Back in August, that was very bad, and plants shut down. Whatever you do, you can't control it." SG19

Another 30% of the industry said that they would install more polytunnels. The highest proportion of these respondents was amongst the small farm enterprises and farms using just the ground production system. Over 50% of growers in Kent also suggested that they would increase the use of polytunnels, compared to only around 20% in Scotland.

Substrate growers thought there is not much they could do, except for a change in variety, whereas around 25% of growers using mixed systems suggested they would add more tabletops.

6.2.1.2.5. Introduction of new pests

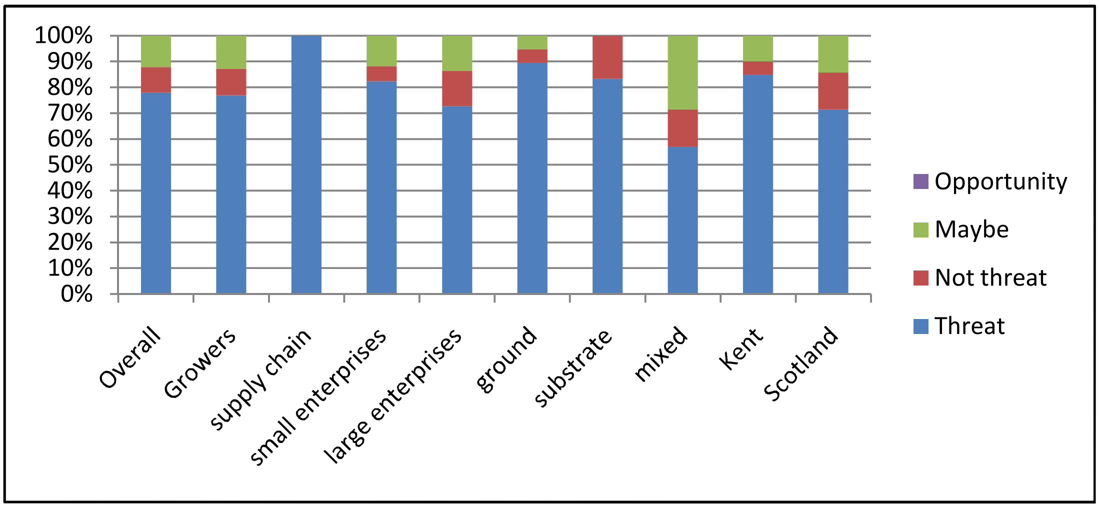


Figure 6-17 How different categories of growers or businesses within the industry see the introduction of new pests as being a potential threat from climate change.

Close to 80% of the industry saw the possible introduction of new pests as a serious threat to the sector (Figure 6-17). The proportion was slightly lower on large farm enterprises. Farms in the mixed production category were again the fewest to see new pests as a threat, with less than 60% of the respondents confirming that it could be a threat. Only slightly more respondents in Kent were concerned about the arrival of new pests than in Scotland, even though the latter were further away from the channel and possible point of entry. Some respondents even suggested that it is already happening and listed one species, Western flower thrip (*Frankliniella occidentalis*) that has become a problem in the recent years.

With respect to adaptation methods (Figure 6-18), just over 40% of the industry suggested getting solutions from other countries where these pests are already a problem and use existing knowledge to control these pests. 30% suggested that they would obtain advice from their agronomist. Around 15% said they would use chemical control, although the proportion was twice as high amongst small enterprises and growers in the ground production category.

Notwithstanding the possible adaptation methods used to control any new pests, the industry was concerned about the limitation of their ability to control them in light of the reduction in the availability of pesticides in the future. To add to that, some suggested that disease resistance build-up could be a greater possibility. As an adaptation to this possibility, a few respondents suggested using biological control, with just under 20% of growers in Kent giving this response.

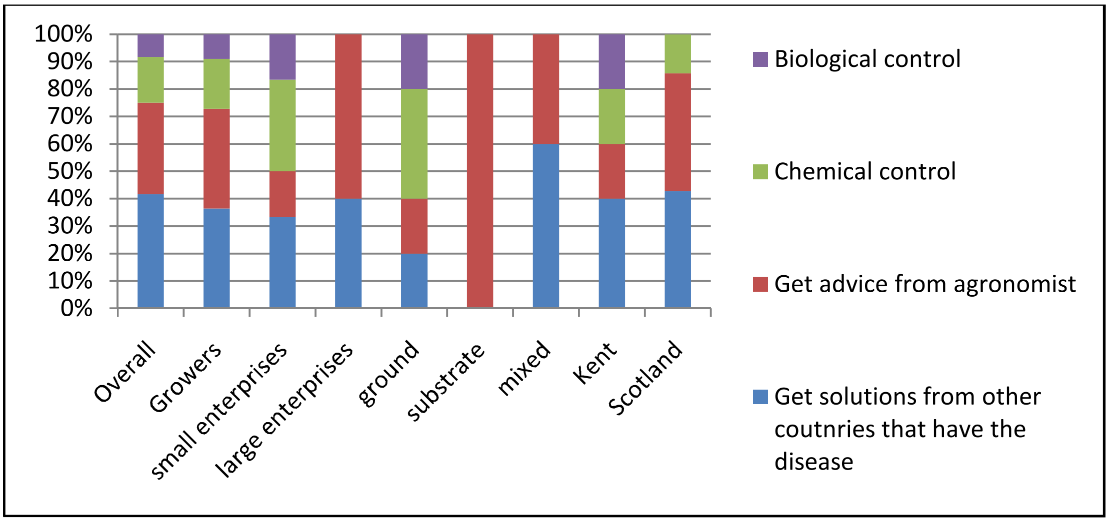


Figure 6-18 Adaptation measures to the introduction of new pests as proposed by different categories of businesses within the industry

6.2.1.2.6. Imports of strawberries and competition with the foreign market

Imports of strawberries into the UK arrive from a number of sources depending on the time of the year, and can be divided into two:

- The winter season when British strawberries are not available. These usually arrive from southern Europe and countries in the Mediterranean region.
- The British strawberry season, when British strawberries are in supply. In this case, the imports come mainly from the Netherlands and the USA. These are usually imported to compensate for a gap in the market when not enough British strawberries are available.

The popularity of the British crop is such that competition with foreign imports is not a big issue, since people in the UK prefer buying British strawberries. Nevertheless, some businesses within the industry see foreign imports as a potential threat. In response to this, many believe that climate change will tip the balance in favour of more sales of British strawberries (Figure 6-19). Just over 55% of the industry believes that climate change will favour the British sector. One grower suggested:

"I think they will find it very difficult to grow good strawberries and get them here because they'll be even hotter than we'll be up here." KG13

This is not only a result of worse climatic conditions in competing countries, but it is also due to the British season becoming longer and the local sector pushing out foreign imports from the shoulder seasons. As the director of a marketing body said:

"I don't think there is a country that could compete with the British strawberries in Summer. We can grow a few more strawberries in summer to push out the remaining summer imports." KS3

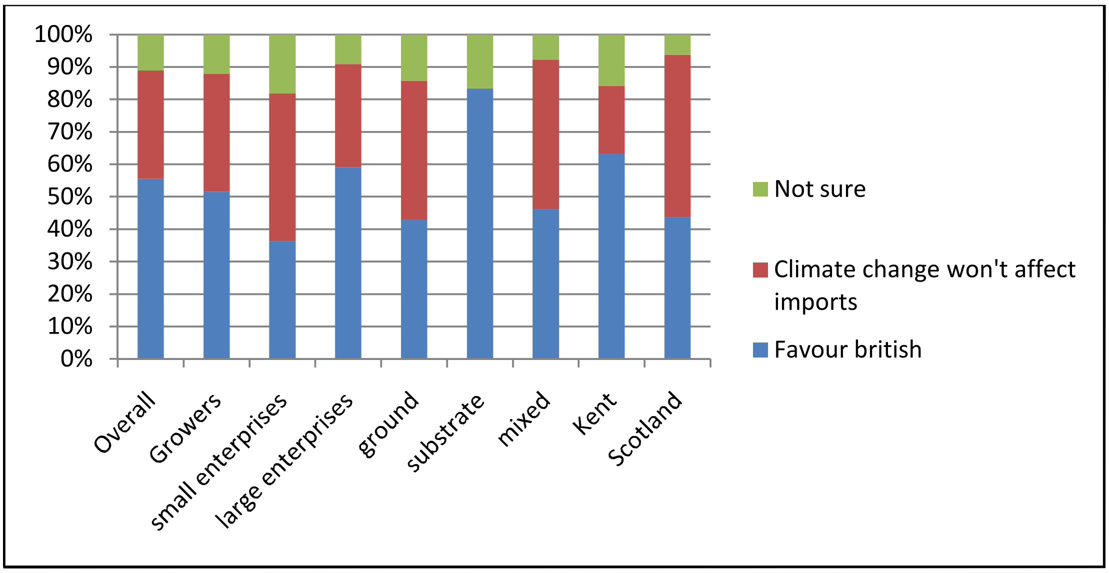


Figure 6-19 How different categories of growers or businesses within the industry believe that climate change will affect strawberry imports.

Others within the industry believed that other factors will have bigger impacts on imports and sales, such as the exchange rate and value of the pound.

6.2.2 Climate change and plant disease

At the initial stages of the social science study, the participants were asked whether or not climate change would have any impact on plant diseases (Figure 6-20). None of them said that it will not. On the contrary, over 80% of them suggested that there would be a varied impact on disease, with some diseases increasing in incidence whilst some others would decrease. Around 60% suggested that there will be more new diseases. Of those suggesting that there will be more disease incidence, a higher proportion were growers from large farm enterprises.

When asked why these changes in disease incidence will occur, there were three groups of responses. One group suggested that botrytis would increase because of milder and wetter winters. Another group suggested that mildew will increase because of warmer summers, whilst some others even said that mildew will decrease in incidence because of the drier summers.

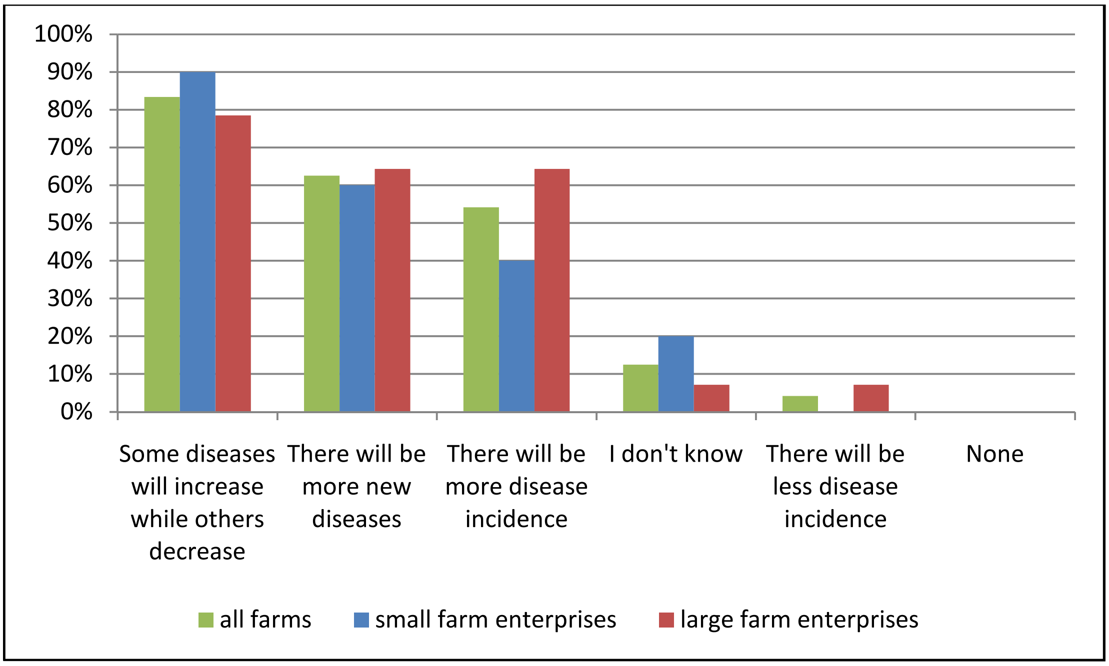


Figure 6-20 Growers' opinions of how climate change will affect disease incidence. Obtained from the questionnaire responses.

After obtaining these responses, the probabilistic projections of disease incidence change with climate change were shown to the participants of the case study interviews. These consisted of forecasts for three diseases (refer to Chapter 5): botrytis, mildew and strawberry black spot.

6.2.2.1. Future disease change and impacts

On investigating the responses obtained (Figure 6-21), as many respondents were sceptical about the impacts of disease on their business as there were who believed that they would be affected. On dividing them geographically, it was seen that only 30% of the respondents from Kent believed that their business would be affected by plant disease, as compared to almost 70% in Scotland. On the other hand, the category for which the highest proportion of sceptical growers was obtained was those using substrate production.

On asking the participants why or how they believe disease will affect them in the future (Figure 6-22), around 30% of them suggested that mildew will be a problem. Another 30% said that the impact of disease will be made worse by the reduction in available chemicals to control disease. Around 14% of all participants also suggested that they are already seeing the same trend happening. The biggest proportion of these was in small farm enterprises and ground based systems that usually use less protection, making them more vulnerable to the prevailing weather. In fact, the same small farm enterprises had amongst the highest proportion of respondents saying that fewer chemicals will make their control of disease worse.

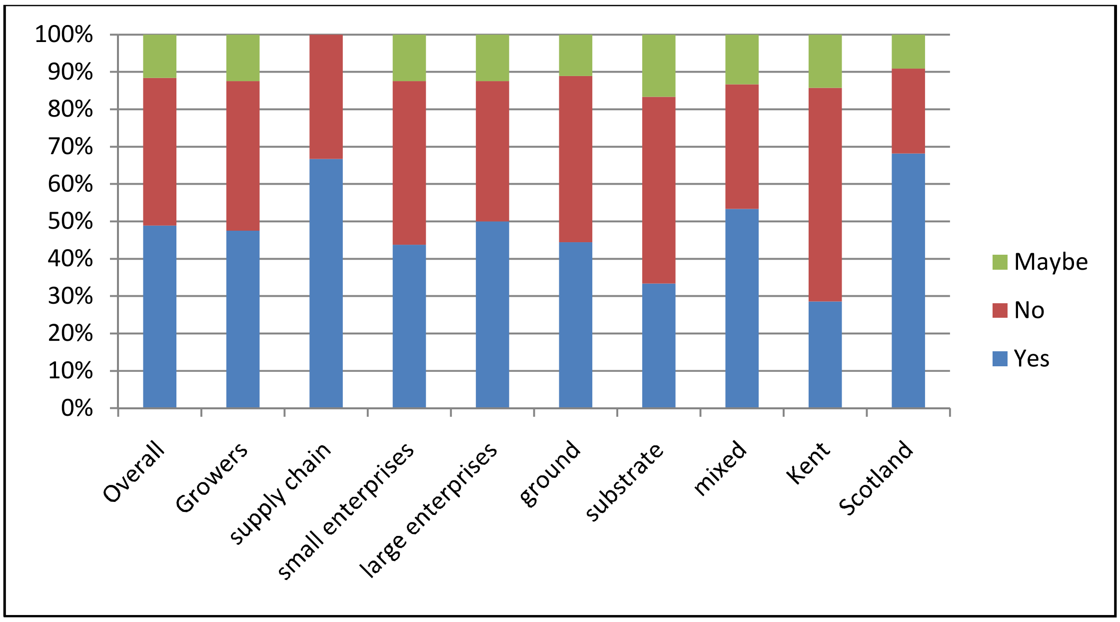


Figure 6-21 Notions of whether the probabilistic projection of disease change with climate change could have an impact on their business (data represent responses for botrytis and mildew).

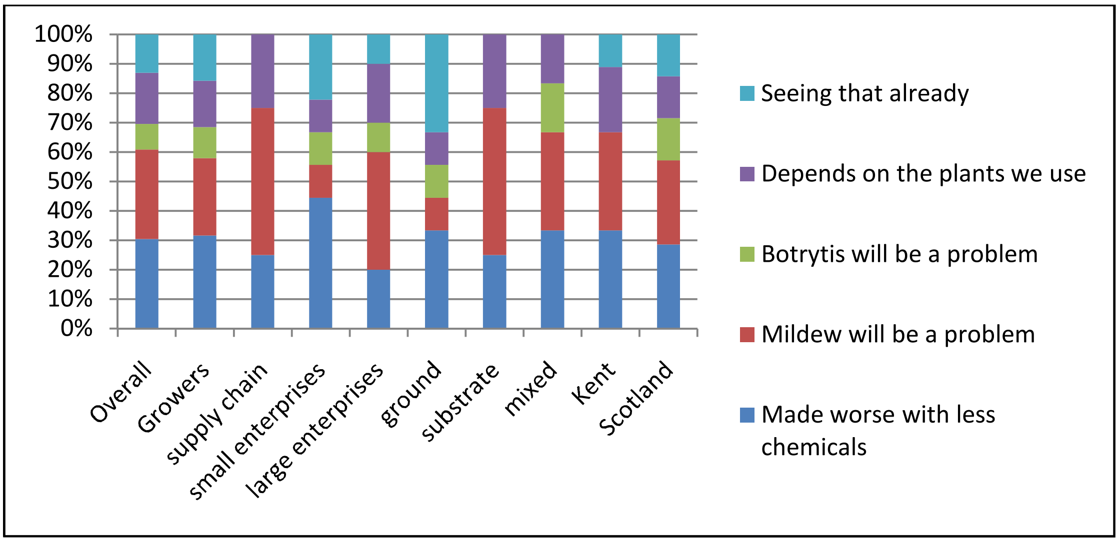


Figure 6-22 Potential impact on business activity through change in disease with climate change

Few believed that botrytis would become a problem and these were either farms using soil based or mixed production farms. None of the substrate-only producers mentioned botrytis as potentially being a problem. On the contrary, almost 50% of growers in this category suggested mildew as being a potential problem in the future, as compared to just over 10% of ground-only producers and growers from small farm enterprises. Growers in large farm enterprises were also concerned about an increase in incidence of mildew in the future, with almost 40% suggesting that scenario.

When the participants were shown the forecasts for black spot, almost 70% of all the respondents suggested that it will not be a problem in the future. The proportion was higher in Kent with all respondents saying that it can be easily controlled and would not pose a risk to their business. As one grower in Kent said:

"Blackspot used to be, "oh god blackspot", and now it's "Blackspot, who cares". No it's not a concern anymore. What stopped blackspot was tunnels. If you cover them [it's ok]." KG19

The only growers that suggested that it could be a problem were growers in Scotland that had never heard of or encountered the disease on their land before.

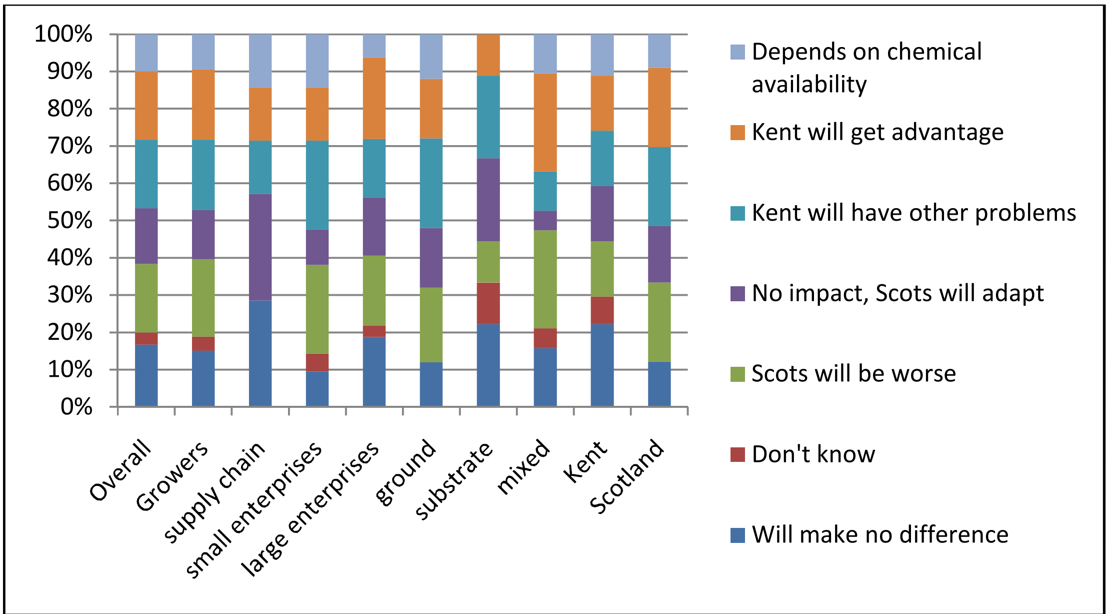


Figure 6-23 Responses to whether regional variation in disease forecast models will have a geographically diverse impact on the industry.

On analysing the differences in impacts on a geographical level (Figure 6-23), around 18% suggested that there will be no difference between impacts on Scottish and Kentish farmers. Nevertheless, just over 35% suggested that Kent will benefit from the change in disease incidence across the UK, to the detriment of Scottish growers. In contrast to this, just over 30% suggested that the Scottish industry will adapt, whist the Kentish strawberry sector will be faced with other problems such as a lack of water and excessive heat. As a grower in Kent suggested:

"Yes probably, but sometimes it could be too hot here, and there in Scotland even if it gets hot up there it will be chillier during the night and will help avoid damage to the strawberries." KG17

And then a Scottish grower said with respect to adaptation:

"Yes it may do but I would suspect that businesses would try to, first of all before they start moving away from one region into another region, businesses will try and overcome the individual problems that they have, so if these become more of a problem we'll try and do other things to overcome these before we consider not growing that crop." SG1

6.2.2.2. Adaptation to change in disease incidence

Ten different adaptive techniques were mentioned (Figure 6-24). The most common was the use of better varieties that are resistant to specific diseases, with over 35% of the respondents suggesting this method. On dividing the responses into categories, around 20% of small farm enterprises suggested adding more tunnels, whilst farms using mixed production systems suggested adding more tabletops for substrate production. Users of polytunnels, such as the large farm enterprises, and substrate users also suggested a change in tunnel design and more ventilation.

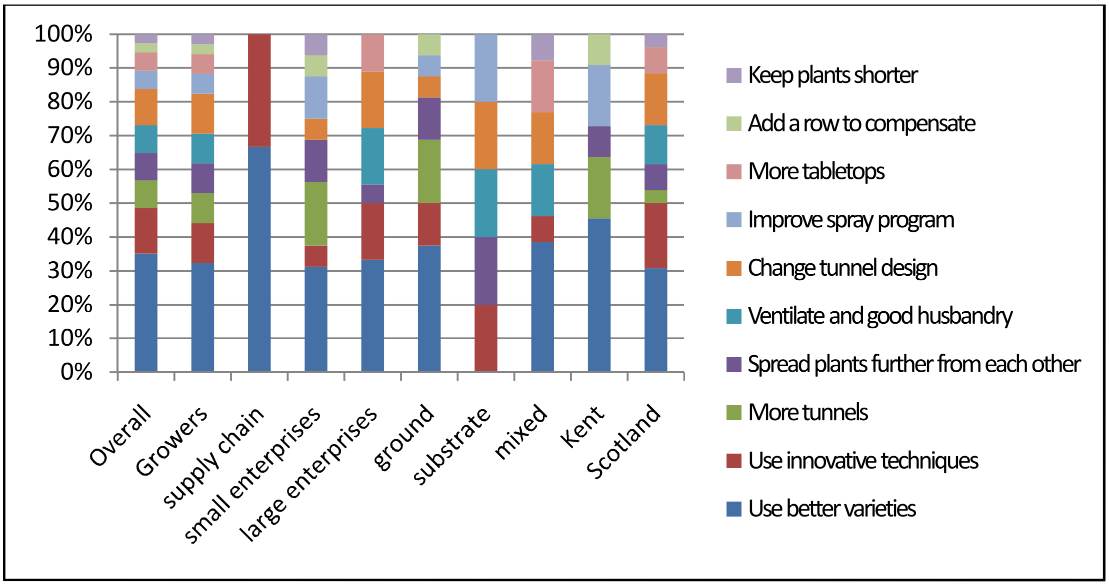


Figure 6-24 Adaptation methods suggested for combating a change in disease incidence with climate change.

Following the discussion with growers about the potential impact of any change in disease, the respondents were asked if they would plan to stop using polytunnels with climate change. Almost 96% said that they would continue using polytunnels irrespective of climate change. One grower explained that:

"No, production out of doors is not an option nowadays. The weather is too unreliable. Whether fruit growing will still be viable or not is another matter." SG11

6.2.3 Opportunities from climate change

As seen earlier, the UK strawberry industry saw an opportunity in almost every climate change scenario that was presented to it. When investigated more closely, 15 different opportunities were mentioned by participants in the study (Figure 6-25). Longer seasons were the most common opportunity, with 39% of the industry responding to it.

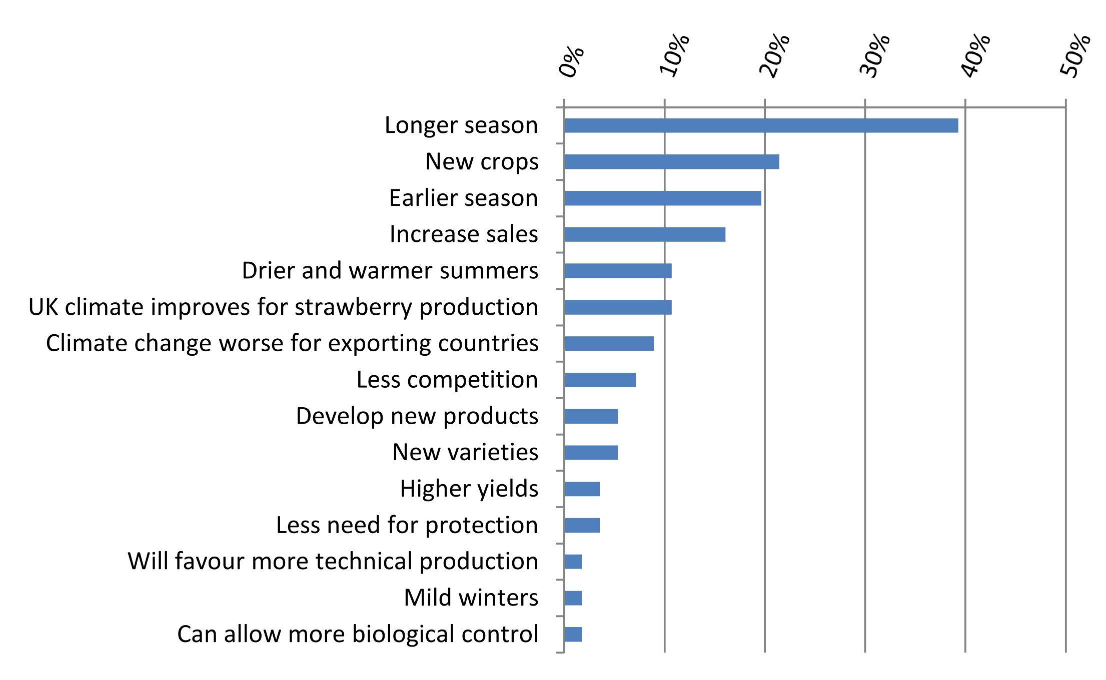


Figure 6-25 Opportunities mentioned by the industry, and the proportions of participants that responded to each opportunity. This data were collected by combining the questionnaire and case study responses.

Of all the opportunities mentioned, growing new crops could be considered as an adaptive technique as a response to a declining business, rather than an opportunity to expand a business. This would however depend on the respondent and could either be to the detriment of the strawberry crop or else as a supplement to it. Through the research, it emerged that it was a mixture of both. A few growers suggested it as an adaptation to climate change, particularly to hot summers which would be detrimental to the production of strawberries. However, most suggested growing new crops as a supplement to strawberries, possibly instead of less profitable crops such as apples. In fact, there is evidence that it is already happening, even amongst some of the growers:

"We are experimenting on a tiny scale with apricots. We've got some peaches in tunnels on a small scale." KG9

On investigating the opportunities by farm size category (Figure 6-26), it was seen that large farm enterprises, that supply most of their crop to supermarkets, are more interested in having an extended season, both longer and earlier. Smaller farm enterprises, on the other hand, were keen to benefit from the drier and warmer summers and an increase in sales, most probably as a result of the former.

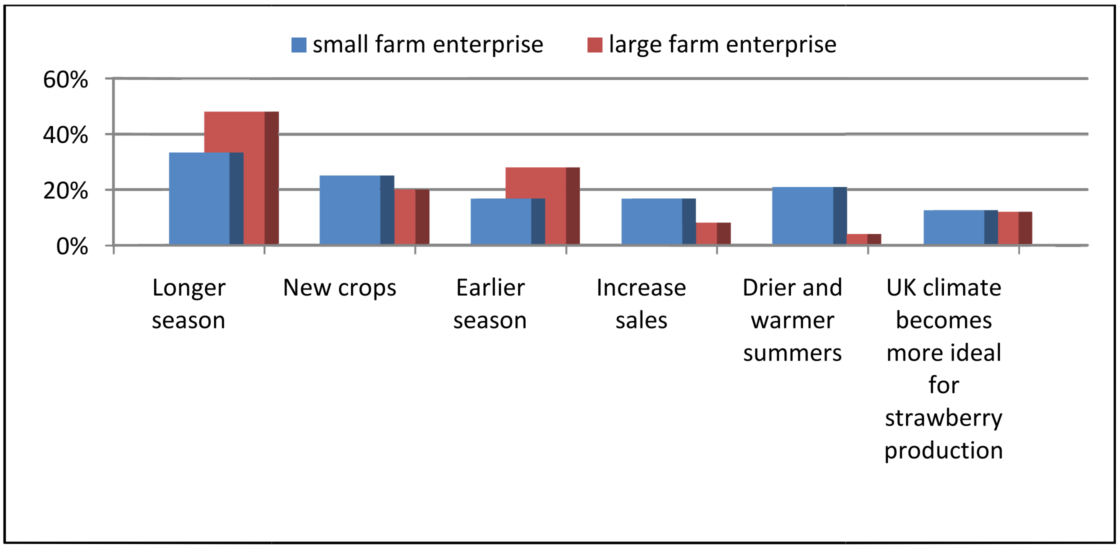


Figure 6-26 Main opportunities mentioned by the industry divided by farm size category. This data were collected by combining the questionnaire and case study responses.

On dividing the farms by growing medium used (Figure 6-27), substrate producers are more interested in producing earlier crops and in developing new markets particularly in exports. Farms using mixed systems were most interested in growing new crops and having a longer season. Farms using solely soil based production systems were hopeful that climate change will bring about an increase in sales from better and warmer weather.

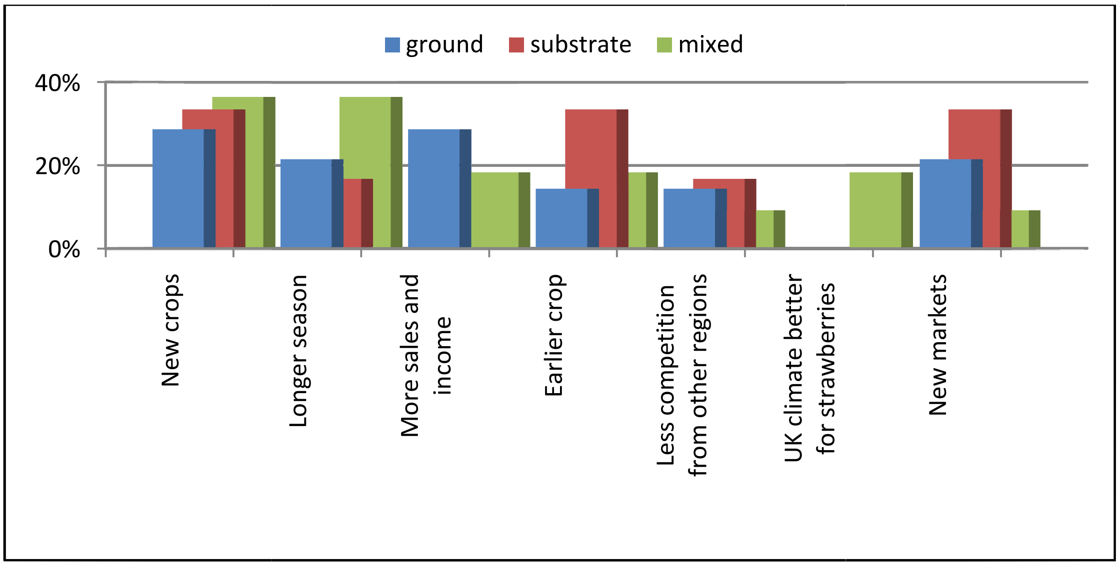


Figure 6-27 Seven main opportunities that emerged from the case study interviews divided by growing medium category.

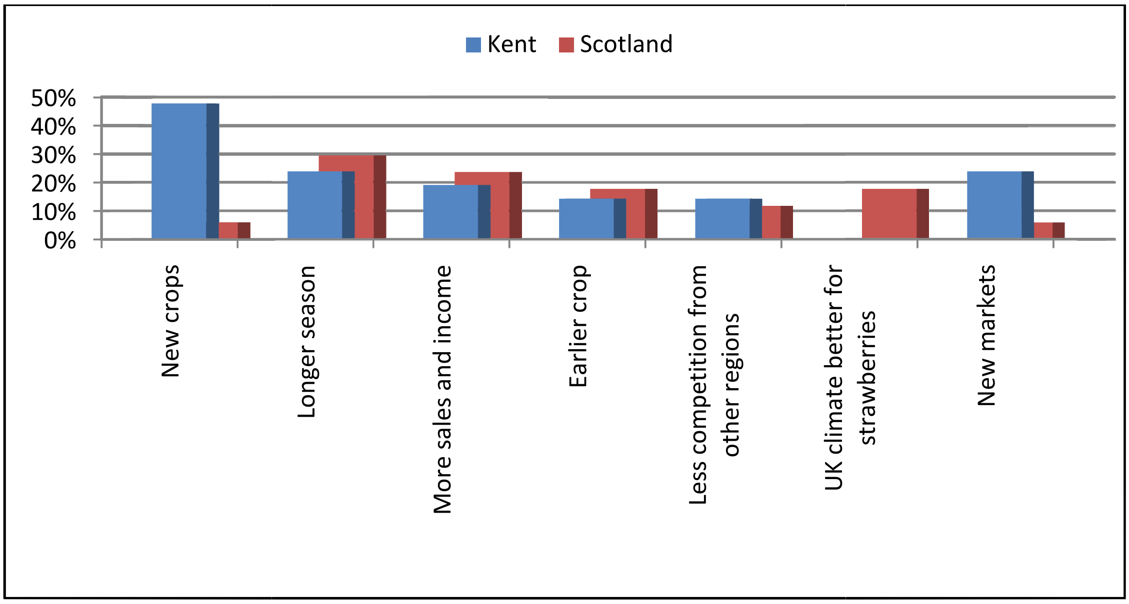


Figure 6-28 Seven main opportunities that emerged from the case study interviews divided by geographic region.

On analysing geographic differences (Figure 6-28) in the opportunities from climate change, the industry in Kent is particularly keen to take advantage of the warmer climate to introduce new crops, whereas the Scottish strawberry industry would be happy with having a better climate to grow strawberries. As one Scottish grower said in relation to opportunities from climate change:

"If it gets very hot in the south of England. We are usually very envious of the conditions obtained by some of our colleagues in the south of England, but

sometimes it gets very hot and the plants shut down from thermo dormancy, so instead of the crops lasting for 5 weeks they last for 3 weeks. When they were having these conditions everyone was saying Scotland is a great place to be ....” SG15

6.2.3.1. Threats vs opportunities

The balance between threats and opportunities was perceived to tip in favour of opportunities, by around 10%. Just over 40% of the respondents believed there would be more opportunities, whilst thirty percent believed there would be more threats (Figure 6-29). Around 15% said that there was an equal balance of threats and opportunities.

On dividing the respondents further into categories, large farm enterprises were more optimistic of the opportunities brought about by climate change, with proportionately twice as many believing there would be more opportunities than small farm enterprises. More of the latter farm category believed that the opportunities will be balanced by the threats equally, whilst around 30% of the small enterprises, as compared to 25% of the large farm enterprises, believed that there were more threats from climate change.

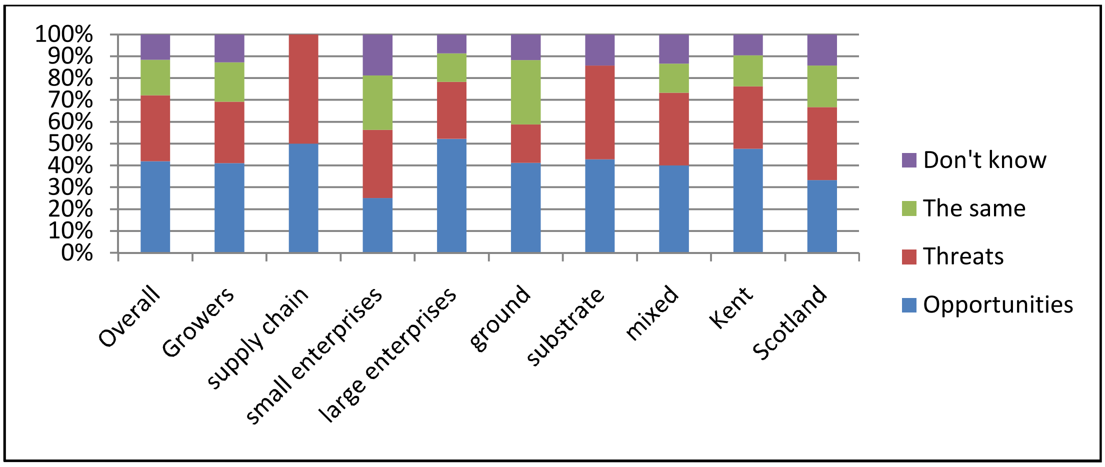


Figure 6-29 How different categories of growers or businesses within the industry see the balance between threats and opportunities brought about by climate change.

The same proportion of users of the different production systems saw more opportunities arising from climate change. More users of substrate systems, however, saw more threats from climate change. On dividing the respondents geographically, it was seen that the industry in Kent is slightly more optimistic about the opportunities than growers in Scotland, by around 10%.

The respondents were also asked to prioritise the opportunities from climate change and identify one opportunity and suggest how they would take advantage of it to the advancement of their business (Figure 6-30). The four main opportunities were associated with improving or changing production, whilst two were related to economic gain. The supply chain is particularly interested in taking advantage of climate change by expanding their business and increasing sales, particularly of polytunnels, specialist products such as IR filters in polythene, and purpose made polytunnels that capture rainfall through a guttering system. One supplier aptly said:

"Strategically if we were asked what business we're in, we'd say it is food security. We're allowing others to produce food. The great things about polytunnels in field scale production, is that .... if that is done well, the ability to produce more output per square metre is significant, ... you can increase yields by 30-35%, you can increase class 1 percentage from 60% to 85-90%. And the other one is to be able to deliver over a prolonged and consistent season. And being less dependent on weather as well. So from that point of view, that's a major opportunity for us, there's drivers for population growth and there's climate change. ... [So what we want to do is] Take advantage of an expanding sector." OS1

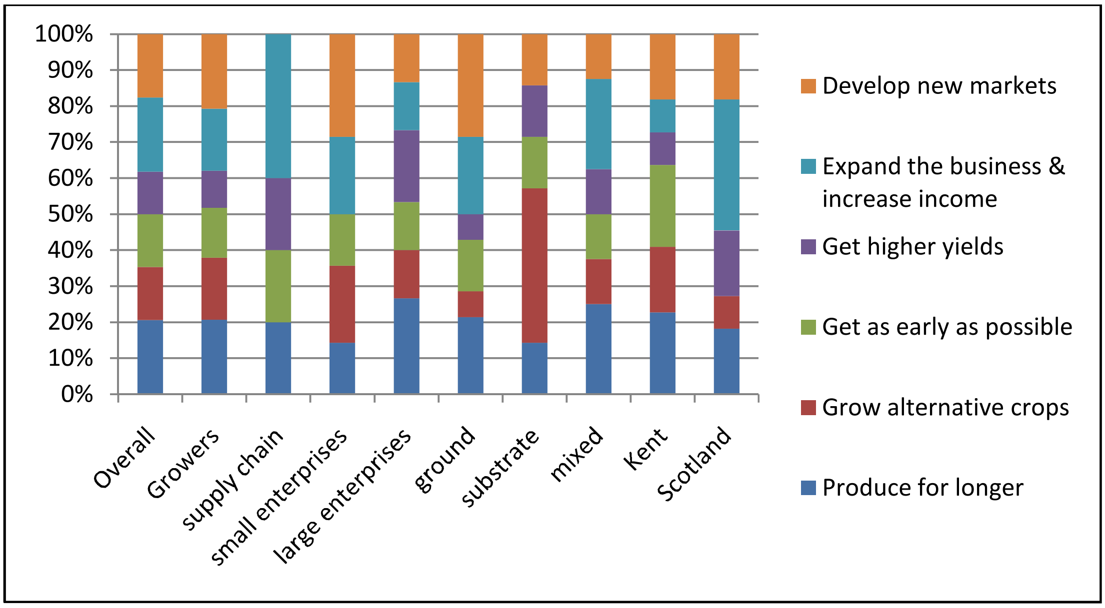


Figure 6-30 Respondents were asked to identify one opportunity from climate change and suggest how they would take advantage of it.

The industry in Scotland was also keen to expand their business thanks to the promise of a better climate to grow strawberries. Small farm enterprises and users of soil based cultivation were eager to develop new markets, be they specialised or export opportunities. Substrate producers were more interested in trying out alternative crops, both as a complement to strawberries but also as a substitute in case the change in climate brings too many threats to the strawberry sector.

"I think I'd grow more raspberries. ... They are more flexible the way they crop, in other words we may go all[the] way through the autumn. They use less water. Less prone to vine weevil." KG13

6.3. DISCUSSION

There is widespread agreement that climate change is a problem affecting society throughout the world. According to the World Development Report on Climate Change and Development commissioned by the World Bank in 2009, it was seen that the public in the 15 countries polled (both developed and developing) saw climate change as a serious problem: either as being very serious or somewhat serious (World Public Opinion, 2010). Moreover, according to a special Euro barometer in 2009 on public opinions, climate change was seen as the second most serious problem faced by the world today after "poverty, the lack of food and drinking water" (European Commission, 2009). In the same report, 45% of respondents in the UK saw climate change as a serious threat. Thus it does not come as a surprise that over half of the people sampled through this study, representing the UK strawberry industry, believe that climate change will also impact them in some way.

The exact way they will be affected, however, varies depending on a number of characteristics, which include the age of the respondents, location of their farm, the production systems they use and the size of their business. And whilst some will be negatively affected, others are optimistic and see opportunities in climate change. For instance, the difference between the ways small and large farm enterprises believe they will be affected arises from the predominant methods of cultivation used by the two farm categories, whereby small farms have most of their production out in the open field, making them feel more vulnerable to climate change and weather variability. The supply chain, on the other hand, are optimistic because they see business opportunities by developing and selling products to farmers that would help them adapt. This variety of opinions agrees with similar studies conducted in other regions of the world, particularly in developed countries where farms have the resources to take advantage of opportunities (Battaglini *et al.*, 2009, Blennow and Persson, 2009).

Amongst the most interesting outcome, was the fact that Scottish respondents were more optimistic than growers in Kent, whilst at the same time admitting that they were just as pessimistic about climate change. The reason for this was that, whilst they expected some climate change scenarios to affect them negatively, such as wetter summers, they saw the overall warming of Great Britain by 1-2^{o}C as bringing a balance to the industry through a geographic shift in crop belts (Hulme *et al.*, 1993). This will give more problems associated with climate change to their competitors in the south and a better and warmer climate for them in Scotland to enable them to obtain an earlier crop and higher yields. In fact, the growers in Kent were concerned about the potential climatic changes mentioned by the Scots as being opportunities for them, such as the drier and warmer summers. This shows why studies on climate impacts should take into consideration geographic dimensions of the country or area of study, since not only do different climatic patterns affect regions differently, but so do local policies and legislation existing in that place. Research conducted on the wine industry in Germany, France and Italy also encountered a divergence of responses between the different countries; this was often due to the prevailing weather conditions, but also to policies existing in those areas (Battaglini *et al.*, 2009). In fact, policy or legislation can often act as a driver of adaptation within a region. For instance, in Kent, being close to a large metropolitan area and being one of the driest areas in Great Britain, the county council puts in place water bans on agricultural enterprises during periods of drought. Eighty percent of Kent's public water supply comes from groundwater and, with climate change, it may become vulnerable to saline intrusion and changes to rainfall patterns (Protect Kent, 2009). In response to this, growers in this area are building water storage facilities to eliminate their dependency on the council's supply of water. This is a case of "autonomous adaptation", whereby the growers do not build water storage facilities as a conscious response to climate change, but are responding to pressures caused by man-made policy in response to water shortages during periods of drought.

Of all the threats mentioned by the industry, extreme events which are predicted to increase in frequency with climate change (Brown *et al.*, 2008b) were seen as the most disconcerting threat. This arose from the growers' concern for potential damage caused to structures on the farm, damage to the crop by either flooding or disease or to over ripening from the inability to reach the crop due to heavy rain and flooding. Damage to polytunnels was one of the worse potential impacts since none of the interviewed growers was insured for damages to their structures from extreme events; thus any damage to the structures would result in years' worth of investment being lost in one event, the cost of which would be borne by the grower. This was a reality for a number of farms that had undergone such damage in the past. In the US alone, the estimated annual economic losses/costs for farmers in years with major weather and climate extremes was of $3.32 billion[28] (Changnon, 2005).

In some instances, the increased risk of damage to polytunnels is not necessarily derived from the increased frequency of extreme events. The extension of the season by the sector in the last 20 years has increased their vulnerability to extreme events. The setting up of polytunnels earlier during the year to get an earlier crop is exposing their structures to winter storms and extreme events such as heavy snow drifts. Whereas usually the structures are removed by late October, and set up again in spring, some growers leave the structures set up throughout the winter, exposing them to a greater risk, which is not necessarily related to climate change. According to research on snow damage to greenhouses by Scarascia-Mugnozza *et al.* (2000), in January 1992, around 400 ha of polytunnels were flattened by snow in the Perpignan region of France, and a year later in January 1993, 100 ha of greenhouses were flattened in the Puglia region by the combined action of heavy snow and strong winds. Moreover, way back in January 1976, a wind storm destroyed a quarter of all the protection structures in England and Wales (Scarascia-Mugnozza *et al.*, 2000). And then polytunnels were not as widespread, with less than 10% of the UK strawberry produce being under cover, compared to over 80% in 2009 (Figure 2-22).

6.3.1 Climate impacts as drivers of innovation

This shift from temporary to fixed and permanent polytunnels has been seen by a few suppliers as a business opportunity, and a number of them have developed stronger polytunnels that are reputed to withstand 100mph winds. They use thicker steel from 1.5” to 2.5”, and stronger multilayer polythene (Chesher, 05 March 2010). In fact, around 25% of the supply chain in the case study interviews suggested that extreme events are not a threat anymore since they believe they have solutions or products that can withstand these forces. Extreme events, such as the severe winter storms that hit the UK in January 2010, are even seen as fuelling the business for a number of these polytunnels suppliers. Some of them reported that requests for stronger polytunnel structures poured in following the severe storms in Scotland, which led to heavy damage to crops and tunnels sustained by some of the growers there (Chesher, 05 March 2010, Watson, 18 March 2010).

[28] this value was calculated for the year 2000 and is not adjusted for inflation.

Other threats from climate change, such as hot summers and drought, are affecting the sector across the UK in different ways. Whilst higher temperatures and drought are a greater threat to the south of Great Britain, the northern regions, such as Scotland, are expected to benefit both directly and indirectly from these scenarios. Not only are they likely to have greater water resources, but there is a high likelihood that more land will be available for strawberry production due to a change in climate (Brown *et al.*, 2008a).

These potential threats from climate change could actually be strong drivers for innovation in the industry. The sector has already invested in introducing innovative tools that could limit the impacts on individual businesses. This has brought about the introduction of specialist polythene films that filter IR radiation, plants that can survive on a tenth of the water supply, sprinkler systems to reduce the heat inside a tunnel, and water catchment and winter storage systems that enable farms to have their own water supply. This drive for innovation is not uncommon and the influence of climate as a driver has been seen in other agricultural sectors both within (Arnell and Delaney, 2006) and outside Great Britain (Smithers and Blay-Palmer, 2001).

Moreover, many farms, particularly those in the south, have already started implementing some of these adaptive techniques, often not being driven directly by climate but sometimes by policy issues and clashes with local authorities (Tompkins *et al.,* 2009). Adaptations in this regard are highly geography dependent and are described as being "*local-scale drivers*" by Hazell and Wood (2008). Other factors influencing adaptation are the financial resources available to a farm. Those having larger turnovers and greater profits are more able to invest in this innovative technology, which can often come at a cost to the business. This is why in most cases the more industrialised countries are better able to adapt to climate change since they have better financial resources to invest in adaptation (Gitay *et al.*, 2001).

Thus farms having water storage capabilities and other techniques for limiting impact of high temperatures could turn a drought into an opportunity by out-competing other farms that would be forced to stop production during such events. This will also bring extra benefits since hot and dry weather generally increases strawberry sales and sometimes also prices in the UK, thus giving advantage to those farms that are best adapted or have more water resources and milder temperatures in their polytunnels. In fact in the TAR, it was estimated that with adaptation, farm incomes are likely to increase with climate change (Easterling and Apps, 2005).

6.3.2 Impacts on pests and disease

There is a feeling amongst the industry that there will be a greater incidence of disease in the future, or whilst some will increase others will decrease. There is also the concept that there will be an increased risk of the introduction of new pests. When coupled with the risk of warmer winters, these risks are seen as a threat to the industry. Whilst this is seen as a realistic threat to global agriculture (Bisgrove and Hadley, 2002, Zhao *et al.*, 2005), some sectors in Europe and in other continents have already recorded evidence of warmer winters occurring (Vedwan and Rhoades, 2001, Battaglini *et al.*, 2009).

This latter phenomenon is particularly worrisome for the strawberry industry because it can affect yield in two different ways. Firstly, if the winters are too warm, the plants will struggle to achieve dormancy. This would in turn affect yields of crop. The second impact would be indirect, through its effect on plant disease, which could lead to increased loss of crop. Cold winters help reduce the disease carryover, thus warmer winters would automatically lead to an increase in disease risk the following season. In a review by Garrett *et al.*, (2006), it was seen that in a number of crop diseases, disease carryover increases following a "warmer" winter. Whilst this has been encountered through this study as a more frequent phenomenon, there was slightly more concern about this in the south of Great Britain, which already experiences milder temperatures than in Scotland. In fact, some of the growers in Scotland saw warmer winters as an opportunity since they've sustained damage to their crops and structures in the past from excessively cold winters. In January 2010, a number of growers lost many of their strawberry plants after the region suffered from temperatures as low as -18°C (Watson, 18 March 2010).

Warmer winters can also have a greater influence on the survival of pests. In another review by Bale *et al.* (2002), on the impact of climate change on insect herbivores, it was seen that the main effect of temperature in temperate regions was the influence on winter survival. This is bound to affect the survival of new pest species which as yet have never become established on the British mainland. Examples of introductions have also been encountered during this study, with growers mentioning one particular case. This explains why almost 80% of the respondents were concerned about the introduction of new pests, not only because the British sector might currently not have the right tools in dealing with these pests, but also because warmer winters will effectively eliminate the natural shield that until now protected British horticulture from most of the invasions of insect pests.

6.3.2.1. Importance of disease forecasting in climate impact studies

Using probabilistic projections to gauge the industry's responses for adaptation is an important tool in climate impact studies. Not only does it help the researcher to get opinions from their respondents, but it helps put the climate change theme into context and make the sector actively think about their adaptation options. Although this technique is relatively new, others have reported the importance of using interdisciplinary research to study how climate change will affect vulnerable agricultural communities (Morton, 2007) since knowledge and awareness of what the impacts of climate change might be would enable farmers to take action, or even consider adaptation tools (Blennow and Persson, 2009, Blackstock *et al.*, 2009). For example, in this study, before growers were actually shown the probabilistic projections, they already had an opinion of how climate change will impact diseases. This awareness arises through the local and national media in the UK, which regularly put climate change in the spotlight, but also due to coverage of climate change in various horticultural magazines aimed at the soft fruit industry. In fact, their main response was right, in that some diseases were being projected to increase whilst others decrease. What they did not expect though is that change will be region specific, with certain regions being predicted to have a greater increase in incidence than others. This triggered a variation in responses, with 86% of growers in Scotland being concerned as compared to only 28% in Kent. It also helped the growers identify which diseases could potentially be a problem.

Nevertheless, whilst the models used to predict the disease incidence for these three diseases were simplistic, and do not take into consideration the evolution of the disease and the impact of winter carryover, they do help as a tool to gauge opinions within the industry on what options are available to adapt to a change in disease incidence. The model also omits to take into consideration the production methods used and the cultivars or varieties, to give leeway to growers to suggest their own adaptation techniques. Three important outcomes emerged from this exercise.

Firstly, the impacts of disease will follow the pattern taken by other climate change impacts, as being regional and location specific in nature. This in turn can follow three patterns. Being highly dependent on weather, the diseases will be weather driven and depend on the prevailing conditions. The incidence will also depend on certain criteria that might be specific to those regions, such as the problem of red core in Scottish farms and the problem with Verticillium wilt in Kent. The balance of diseases might also change, with a disease that was previously not a problem in one area becoming a serious problem with climate change. This could give certain advantages to one region over another, unless that disease can be easily controlled.

Secondly, a number of options for adaptation could be available, the most common of which was the use of better varieties. The only limitation identified in the case study interviews is that the biggest driver for developing new varieties, at least in the UK, is for varieties giving the tastiest strawberries, with the best shape and the highest proportion of first class fruit. Disease resistance is not the highest on the agenda. Thus while growers hope for a miracle variety that would save them from a change in disease incidence with climate change, the supply chain is lagging in providing a suitable solution, partly because they might not be aware of the extent of predicted diseases changes.

Thus in the absence of an improved variety, growers will need to resort to other effective methods of controlling disease, which brings us to the third outcome; the increased dependence of the sector on pesticides and fungicides. This will not necessarily be a sustainable solution, since potentially more chemicals could be lost in the future following the enactment of EC Regulation No 1107/2009 concerning the placing of plant protection products on the market. This regulation, that repealed Council Directives 79/117/EEC and 91/414/EEC in 21 October 2009, will enable the setting up of a list of permitted active ingredients, and requirements for their approval, by 14th June 2011. What is different in this Regulation is that the precautionary principle will be applied to "*ensure that industry demonstrates that substances or products produced or placed on the market do not have any harmful effect on human or animal health or any unacceptable effects on the environment*" (Anonymous, 2009a). This could potentially reduce the availability of pesticides for the strawberry sector, making them highly vulnerable to the impacts of plant disease and climate change. Moreover, as was seen from the interviews with suppliers to the industry, little research is being conducted on developing new products for the soft fruit industry since it is considered as a small market. This was echoed by (Nauen *et al.*, 2008) who suggested that the ones that will be most vulnerable to this new legislation are the growers of "minor crops" since "the availability of pesticides to them is already very limited, threatening the sustainability of production of their crops." This was echoed within the strawberry industry, where around 90% of growers were concerned by the changes in legislation (See section 4.4.1.3.1). Without the availability of the right chemicals, strawberry production could become highly vulnerable to any changes in disease incidence. One of the leading suppliers of plants in the UK, suggested that a reduction in pesticides could force all the breeding programmes to focus on disease resistance; however, this will come at a cost since it could be at least 10 years before a new variety is developed, and the sector might have changed beyond recognition by then.

6.3.3 Opportunities from climate change

Like any risk, climate change can bring threats as well as opportunities. Some individuals can turn the potential risk into economic gain. This is also true for agriculture and climate change and, whilst some countries will benefit from an "improvement" in the available climate, others have suggested that, if adaptation is done at an early stage, it could lead to economic gain for those farms that have started adapting (Howden *et al.*, 2007, Tubiello *et al.*, 2008). This is also true for the British strawberry industry. Through this study, four types of opportunities from climate change were encountered:

Directly-gained opportunities: these are opportunities gained from an improvement in the climate for strawberry production. An increase in temperature would mean earlier springs, a lengthening of the season, increased use of biological control and also higher yields in regions which are currently limited by cool summers. Less rainfall in summer would bring a reduction in fungal disease in outside crops during that season. Milder winters would bring advantages in the northern limits of production by subjecting the crop to less frost damage. All these opportunities, however, are highly region specific and might bring advantages to certain regions to the detriment of others. This was particularly clear in the strawberry sector, where Scottish growers were expecting to enjoy better weather conditions in the future.

Opportunities from adaptation: Those farms that will adapt early through technological innovation will be in a better position to take advantage of the threats brought about through climate change. Examples of this include those growers in Kent that will have water storage facilities or farms that have IR filtering polythene films and misting systems, and those that have raised their plants off the ground to avoid soil borne diseases. Therefore, whilst climate change will adversely affect other farms, the farms that have adapted will be able to remain profitable.

Opportunities from taking advantage of impacts on others: In this case, those growers that are better adapted, or are located within regions that will get a better climate, will be able to take up business from those that have been adversely affected. This includes the British strawberry industry as a whole, replacing imports due to negative impacts on countries which are further south, such as Spain. This could also bring about export opportunities for the British strawberry industry, with the UK potentially becoming a net exporter of strawberries in the future. It could also happen on a regional scale such as between Scotland and Kent, with the former increasing in size and productivity to take up the business of farms in Kent that were adversely affected. It could also occur on a local scale, with adapted growers in a region that is negatively affected taking up business of other neighbouring farms that have been adversely affected.

Opportunities from a change in market: A warmer climate and drier summers could potentially lead to an increase in demand. This could result in an increase in sales, with growers increasing further in size. Suppliers would also take advantage of the drive for adaptation and innovation by developing and selling new products that will help the sector adapt.

The UK strawberry sector is exposed to a number of these opportunity scenarios and it is expected that some growers will benefit more than others. Large farm enterprises for instance were more optimistic and the majority saw more opportunities with climate change. The main reason for this was their greater financial resources as compared to small farm enterprises. For the latter, adaptation would come at a greater cost and it was not surprising that almost twice as many small farm enterprises were prepared to change crop. In fact, this latter opportunity was referred to both as a substitute for strawberries and also as a supplement. For large farms, it was suggested mostly as a supplement since they have already invested heavily in polytunnels and equipment specific for strawberry production; thus a replacement of the crop with something else could potentially come at greater expense than trying to adapt. Smaller farms, on the other hand, are freer to change crop since they have not invested the same type of money in infrastructure and equipment, and have less of their income coming from strawberries, so they can shift with potentially little economic impact on the farm.

6.4. SYNTHESIS

Through this study, evidence has been found that climate change is already affecting the strawberry sector. Events attributed to climate change, such as an increase in incidence of extreme weather events, hotter summers, warmer winters and earlier springs, have all been encountered by farms throughout the UK. Many farms have already been adversely affected and suffered financial loss from such events. This has triggered those with financial reserves to adapt by buying new products that would enable them to survive future climate challenges. This in turn has driven innovation within the sector, sometimes as a direct result of companies involved in strawberry production funding research and development to develop new products, either by the company themselves or else through collaboration with Universities by funding their research. Nevertheless, innovation has also come through other drivers. These include local policies (e.g. on water usage) and, in some cases, National and EU legislation (e.g. ban of methyl bromide).

This drive for adaptation has come not necessarily from the growers' willingness to adapt to climate change but rather as a means to survive, by guaranteeing the economic sustainability of the farm. This has been seen in other sectors and Mertz *et al.* (2009) suggest that growers adapt to economic challenges rather than to climate change *per se,* thus "autonomous adaptation" in favour of "planned adaptation". Nevertheless, as long as there is a market, there will always be a product developed to sell to that market. For the strawberry sector, this would involve two markets - the first being the demand for British strawberries, which would sustain the existence of the British strawberry growers, and the second being the market for products feeding into the sector, and enabling the sector to adapt to the challenges of climate change.

As long as these two markets are large enough and sustainable, the British strawberry sector will survive. Farms that are adapted, or have the resources to adapt, will survive and in some cases take advantage of climate change by increasing their sales either as a result of an increase in yield from a better climate or through a decrease in competition.

Thus the strength of the British strawberry sector lies in its ability to re-invent itself, as it has done in the past to survive challenges from policy and supermarket dominance. Innovation comes from within the sector and the pioneers and large growers tend to be the leaders and often chairs or board members of various producer organisations.

Notwithstanding its resilience in the past, the strawberry industry has relied on the use of plant protection products to sustain its phenomenal growth. As a result, the greatest threat of climate change on the sector would probably be from plant disease as an indirect impact on the changes in availability of plant protection products in the future. If these were limited, the next best option would either be to have new products or disease resistant varieties. Unfortunately, the supply chain is particularly lacking in this regard since research and development into new products or plant varieties are still lacking. Moreover, for a new product to be placed on the market it might take a decade from its inception and, at this stage, there are serious doubts from within the sector that the supply chain will be able to provide the disease resistant varieties and new plant protection products that will help tackle the challenges of a potential change in disease incidence in the future.

In the absence of these two, growers will need to capitalise on cultural methods and change their forms of production to reduce loss of crop from disease. Biological control will become more widespread and the grower will have to pay more attention to detail in the production of the crop. Inevitably, those that are least adapted, have lower profit margins and fewer financial resources to invest in adaptive techniques will leave the sector. The sector will become smaller and the survivors will increase production to replace the sales lost by growers that left the business. If the survivors are unable to increase their production because of their inability to control plant disease effectively, there will be a lack of supply.

Thus, while the British strawberry sector is optimistic about its future with regards to the opportunities of climate change, the ability or inability to control plant disease in the future could be one of its biggest challenges. This is particularly the case in the countries subject to European legislation and can have implications for other similar agricultural sectors, which are relatively small in size. Unless research and development into effective methods of combating plant disease and providing new safe plant protection products or resistant varieties is forthcoming, food security within Europe can become a major issue.

Chapter 7 Conclusions

The purpose of this chapter is to give a general overview of the key findings of the study in light of their original contribution to knowledge. It first starts by discussing the key findings and assessing the achievements of the study. It then links the outcomes back to the objectives and assesses some of the methodology used. The implications of the general outcomes are then discussed in light of what they mean to the strawberry industry and policymakers. Finally, some recommendations are made for further research relating to some of the findings.

7.1. KEY FINDINGS AND ACHIEVEMENTS

As the world population continues to increase by another 2-4 billion people by 2050, the world's agricultural resources will be put under formidable pressure to produce enough food to feed everyone (Cohen, 2003). The outcome is expected to be even bleaker when climate change is taken into consideration, as the latter has widely been projected to pose an increasing threat to food security (Schmidhuber and Tubiello, 2007). One way to reduce the potential impact on food security is to minimise crop loss from plant disease. However, in order to do this one first needs to know how climate change might affect plant disease. This, in turn, also requires an understanding of the individual grower's ability to continue producing food, in order to come up with adaptation techniques that mitigate any potential impact.

Although the number of studies that have developed disease forecast models has been increasing, with increasingly complex models (Booth *et al.*, 2000, Bergot *et al.*, 2004, Salinari *et al.*, 2006, Evans *et al.*, 2008, Turner, 2008), these studies fall short of assessing the social and economic impacts on the farms themselves and on the wider agricultural sector that is being studied (Barnes *et al.*, 2010). Studies that are in essence interdisciplinary, linking the natural and social sciences, are increasingly seen as being essential in developing solutions to adaptation in vulnerable sectors (Rosenzweig and Wilbanks, 2010).

Through the objectives laid out in the introduction to this study, the need for an interdisciplinary approach to climate change impact studies is being addressed. The study combines natural and social science methods to generate data on a wide range of themes, some of which have rarely been examined in the published literature. An assessment of the data and themes has enabled a better understanding on how different challenges, whether or not related to climate change, interact with each other and may potentially affect the strawberry sector. Solutions for adaptation have come from the strawberry sector itself rather than from the academics involved in the study, and much evidence has emerged that the sector is already adapting and has been for the last 15-20 years. Moreover, the data have provided a wealth of knowledge on a range of topics, including: plant disease, agricultural restructuring, climate change, resilience, adaptation, farm dynamics and economics, and regulatory issues. Most importantly though, this study has managed to combine all of these to generate an original contribution to science by possibly being the first to link plant disease modelling with social science tools in order to develop solutions to adaptation in an agricultural sector in a changing climate. It is probably also the first such study to cover the past, present and future restructuring of an agricultural sector. It does so by linking the lessons learnt from past and present challenges with modelled impacts to come up with a scenario of what future change will bring about in light of adaptation solutions emerging from the British strawberry industry.

In view of the approach taken and some of the methods used, a number of unique outcomes were achieved in this study. A highlight of the six major outcomes now follows:

The first major outcome is that the introduction of polytunnels in the mid 1990s was found to be the most important factor affecting the transformation of strawberry cultivation in the UK, from being a minor crop to becoming an industry with a specialist supply chain. This was brought about through the drastic increase in crop yields and turnover per hectare in those farms using polytunnels. This in turn fuelled further growth within individual businesses as farms became larger. The use of polytunnels also decreased the impact of weather on the crop, thus bridging the difference in yields obtained between Scottish and English farms. As a result, growers in areas previously disadvantaged by the weather could now grow strawberries competitively. This brought a shift in the geography of strawberry cultivation in the UK, to those areas where large strawberry farms using polytunnels were concentrated. The restructuring seen in this sector was different to that seen in the major agricultural sectors (Ilbery and Watts, 2003) since it happened later and was driven by the strawberry sector itself rather than government policies that favoured other sectors. This set of outcomes addresses the first objective of this study, which was to examine the history of the strawberry sector and changes in practices used from 1920 to 2009. This was made possible through the methodology used and the availability of agricultural statistics. These datasets were very useful in observing long term change in the strawberry sector and also in assessing the influence of some of the factors affecting change. Without the availability of these datasets, the same level of detail could not have been achieved. The quantitative nature of the data meant that a number of statistical tests could be applied to test for significance in the trends. Notwithstanding this, there were a number of downfalls to the use of these datasets. Firstly, many different sources had to be used to build a long time series, which meant that it took a lot of time to collect all the data, and various authorities had to be chased to provide enough data to populate the series. Secondly, some of the datasets were discontinuous and did not cover the whole time series. This meant that some of the information was missing, particularly for the earlier years covered by the study, limiting somewhat the amount of inference that could be made on this early phase of the strawberry sector.

The second major outcome of this study was that plant disease was seen as being a driver of change in the strawberry sector between 1920 and 2009, mainly through a change in cultivation practices to control plant disease. Some of these included the development of disease resistant strawberry cultivars, increased use of plant protection products and new cultivation practices such as substrate production. Plant disease was also seen to affect differentiation in the strawberry sector through the way different diseases affected crop production differently in various regions. These outcomes emerged from the second objective of this study, which was to examine the historiography of plant disease in the UK between 1920 and 2009. This was made possible through the examination of the disease datasets obtained from FERA. The level of detail available in the datasets allowed the generation of assumptions on trends of disease incidence in both space and time over a relatively long time period. They also gave an indication of what were the most important diseases affecting strawberry cultivation over the years and how their influence on the sector changed. The use of Genstat and ArcMap was particularly useful in giving significance to some of these trends, especially with respect to the link between rainfall/soil drainage capacity and red core outbreaks. Their biggest drawback, however, was that the records were not representative of the actual occurrence of disease outbreaks. There inevitably were many disease outbreaks that were not recorded by the PHSI during the 90 years of records. This meant that it was not possible to study weather and disease incidence interactions in more detail, since the exact date of the disease outbreaks was not known. This made it impossible to link the disease events to a particular or specific weather pattern consistently over the 90 year period.

The third major outcome is that two types of strawberry farms exist within the UK strawberry industry. Everything within these farm types was found to be different, including the production methods used, the yield, size of farms, the way they sold their crops, and even the way they dealt with disease. This inevitably affected the way they responded to challenges facing the industry in the last two decades, leading to a further divergence between the two farm categories. This outcome emerged from the third objective of this study, which was to examine recent restructuring in the UK strawberry sector. The objective was achieved through the use of a social science study targeting the UK strawberry sector. The advantage of using social science to generate data for this objective was that it permitted a better understanding of the processes affecting change in the strawberry industry. It also provided information on how important the various drivers were and how they fitted together. Quantitative sources of data would not have been able to provide such information and in such detail. The only difficulty one might add is that the data were not “quantitative enough” to allow further statistical analysis to test the significance of some of the trends and responses. In reality, rather than being a disadvantage, the qualitative nature of these data gave strength to the study, since statistical analysis can sometimes nullify and not properly explain trends that are not evident. Moreover, using qualitative techniques of data collection allows the researcher to obtain information on processes that he/she was previously unaware of and a broader range on information than would have been possible by using quantitative data only (Sarantakos, 1994).

The fourth major outcome of this study was that the UK strawberry sector has increasingly become dependent on the use of plant protection products to maintain its phenomenal growth in the last two decades. The potential loss of plant protection products through the introduction of EC Regulation (EC) No 1107/2009 (Anonymous, 2009a) was seen as the second biggest challenge facing the sector. This vulnerability increases in light of the lack of development of disease resistant cultivars and new plant protection products by the producers supplying the strawberry sector. Moreover, the sector is vulnerable to the impact of non-native diseases through the potential entry of pathogens on imported plant material as a result of weaknesses in the existing phytosanitary system. These outcomes emerged from the second and third objectives of this study, which focused respectively on the analysis of the historiography of plant disease (weaknesses of Phytosanitary systems) and the role of plant disease in the restructuring of the sector (dependence on pesticides). The methodology used to generate these outcomes made use of both disease datasets for *Colletotrichum acutatum* and data generated in the social science study. In this case, the disease datasets were more detailed and gave potential for greater interpretation of the results. The social science data, on the other hand, allowed the researcher to rank the importance of plant protection products for the sector and provided ample evidence of the vulnerability of the sector to a potential reduction in their availability.

The fifth major outcome of this study was the temporal and spatial change in potential disease incidence with climate change. The potential incidence of three different diseases was predicted to change with climate change, with each disease showing different patterns of change depending on the location, timeframe and emission scenario. This outcome was in response to the fourth objective of this study, which was to forecast disease prevalence in the UK strawberry sector using various climate change scenarios. This was achieved by modelling disease forecasts and combining them with probabilistic projections of climate change through the use of a number of statistical tools and models. This enabled the generation of the probabilistic projections described in chapter 5. As explained in the discussion of that chapter, the models are simplistic; however, they provided insight into the extent of geographic changes in incidence of plant disease that may potentially face the UK strawberry sector. The methodology used could be applied to predict other events or climatic variables by policy makers or even the strawberry sector itself, even with a very basic knowledge of modelling. Events such as the length of the season, extreme events, temperature thresholds and other weather events can be predicted both on a local and national scale. This could provide the sector with knowledge of potential impacts and pre-empt it to adapt in favour of planned adaptation as opposed to autonomous adaptation.

The sixth major outcome of this study was that the strawberry sector has been unknowingly adapting to climate change by responding to local challenges facing the sector in the last two decades through the introduction of innovative technology. In spite of this adaptation, the UK strawberry sector is still vulnerable to the impact of climate change on plant disease, depending on the ability of the sector to control plant disease in the future with the coming into force of EC Regulation (EC) No 1107/2009 (Anonymous, 2009a). A reduction in pesticide availability, together with a change in disease incidence, could bring about a change in the shape of the strawberry sector within the next two decades. This outcome was achieved in response to the fifth objective of this study, which attempted to examine the adaptability and vulnerability of the sector in response to the potential impacts of climate change. The methodology used to achieve this objective was based on social science techniques. By using these techniques, a number of processes to which the researcher was unaware emerged, such as innovation coming from within the strawberry sector through products developed by entrepreneurial strawberry growers. The technique also allowed growers to provide solutions to adaptation themselves, thus allowing for a better assessment of the adaptability of the sector. The use of semi-structured interviews also allowed growers the freedom to emphasize topics which were important to them, such as the potential opportunities that could be brought about by a changing climate.

7.2. USE OF MULTIDISCIPLINARY VS INTERDISCIPLINARY SCIENCE

The call for interdisciplinary research has become widespread in the last five years as it is increasingly being seen as the way to find solutions to many of the issues facing society in this century (Bracken and Oughton, 2009). This is even more so when studying climate change and adaptation, as the interaction between human responses and climate impacts provides a playground with unlimited potential for interdisciplinary research (Lynch *et al.*, 2008, Rosenzweig and Wilbanks, 2010). However, these calls are not new as certain climate scientists have been stressing the need for interdisciplinary research for at least three decades (Schneider, 1977, Chen, 1981). Notwithstanding this, interdisciplinary studies of climate change are still infrequent, and most researchers prefer to stay within their comfort zone and stick to their own discipline (Lynch *et al.*, 2008).

One of the problems of interdisciplinary research is that not all researchers have the same concept of what it entails (Lau and Pasquini, 2008). Various levels of disciplinarity exist such as mutli-disciplinarity, transdisciplinarity and interdisciplinarity, with researchers from different backgrounds having different opinions on what they involve (Lau and Pasquini, 2008). The most widely accepted view, however, is that multidisciplinarity involves the use of tools from different disciplines separately to come up with solutions to a problem. Interdisciplinarity, on the other hand, is when the focus of combining disciplines is in the process or methodology and not the domain (Youngblood, 2007). Thus different disciplines are combined to come up with a new methodology. In view of this, this study is primarily multidisciplinary but interdisciplinary at different stages. It is multidisciplinary in that tools and methods from various fields such as plant pathology, statistics, modelling and social science are used separately to provide results that, when combined, help to suggest reasons that explain the observed trends. On the other hand, it is moving towards interdisciplinarity in using probabilistic projections of plant disease in the interviewing process to elicit and stimulate interaction with the respondents on adaptation to climate change. This methodology is innovative in its application, but also in its effectiveness in engaging with the responses of an industry to an interviewing process. It was, in fact, the part of the interview which the growers asked most questions about and viewed with most interest. In the researcher's view, it even encouraged snowballing as the respondents became keen to recommend the names of other potential interviewees. In the absence of the use of disease forecast models in the interviewing process, the level of interaction with the stakeholders might not have been the same.

7.3. IMPACT AND OUTREACH OF THE STUDY

The implications of this study are more far reaching than for the strawberry sector alone. The restructuring of the strawberry sector is indirectly affecting other horticultural crops. Technology developed for the strawberry sector is increasingly used in other crops and some of the large growers encountered in this study were also key growers of other crops including various soft fruit, apples, tomatoes and even radishes. Intensification in the horticultural industry has been seen to be widespread and is partly affected by an increase in power of the retail sector (Rogaly, 2008). Problems encountered in strawberries could potentially affect other sectors too. Probably the biggest threat is the potential reduction in availability of plant protection products which could negatively affect the whole horticultural industry (Pesticides Safety Directorate, 2008). Development of new plant protection products for minor crops is not a priority for the big chemical companies since the potential income might not outweigh the costs involved in product development and registration (Balderacchi and Trevisan, 2010). Strawberries were only the 76th major crop worldwide in 2008 (FAOSTAT), and the level of investment in developing new products was seen through this study as being insignificant compared to what is being developed for major crops.

In view of the potential limitations brought by new EU regulation, the strawberry sector will be hard pressed to find new ways of controlling disease. The lessons learnt from the historiography of disease incidence in the UK show that the sector must be allowed to be flexible enough to move production to regions where incidence of the major, or most economically damaging, diseases is low. This would be a solution for those growers using ground cultivation and who need further new land to apply longer crop rotations. However, it was seen through this study that even though growers are increasingly renting land, they are reluctant to uproot their business and move to other regions. Alternatively, they prefer to raise their crop off the ground and increasingly resort to technological methods of controlling disease. This inevitably brings conflicts in regions where the local authorities view the extensive use of polytunnels as a threat. On the other hand, in regions such as the east of Scotland, where such restrictions do not exist, businesses will be able to thrive not only due to their unrestricted use of polytunnels, but also because the size of farms there allows growers to rotate the crop within their own land. The implications are for a potential migration of the UK strawberry sector in the next two decades to regions encouraging intensive horticulture. This also applies to the rest of the horticultural industry and could potentially lead to the process of concentration (Ilbery and Maye, 2010) of the horticultural industry as has happened with British arable and livestock farming (Ilbery, 1988).

In view of the potential change in climatic conditions and disease incidence, the strawberry sector should be allowed to adapt itself to face these challenges. Most adaptation in the sector in the past has come from within the strawberry sector, mostly in response to existing challenges as has been observed in other sectors in the UK (Tompkins *et al.*, 2009, Arnell and Delaney, 2006). The overwhelming response to adaptation has been from large farm enterprises, which through an increase in income are able to adapt themselves by investing in technology. This “preparedness” will not just help them survive climate change, but they could even take advantage of some of the opportunities that may arise (Howden *et al.*, 2007, Tubiello *et al.*, 2008). In view of this, for British strawberry production to survive climate change, policymakers should introduce policies that encourage adaptation rather than policies that hinder it. If clashes between the industry and local government, as have been seen in the past, become widespread (Hickman, 26 June 2006, Doward, 4 July 2010), the sector will not be able to take advantage of the potential opportunities brought about by climate change, and may potentially lose their market share of supermarket sales to foreign imports.

As a final point, one would probably ask what would happen to the small farm enterprises as a consequence of climate change. Would they decrease in overall number? The answer to that is most probably yes. As their market share decreases further, probably as a result of growth in large farm enterprises, more of them will go out of business, or rather stop growing strawberries. The ones that do survive will almost entirely depend on the public's demand for more novel and niche sources of food (Holloway *et al.*, 2007). Footfall will be the factor that will tip the scales, so the survivors will most probably be in the urban fringe, or close to large towns (Blair, 1980, Ilbery and Maye, 2010). Climate change, on the other hand, might affect this farm category; however, any potential impacts will not be the driving force for these growers to stop growing strawberries. Their biggest driving force will be access to the market. Growers in this category were seen to be able to withstand a certain amount of loss of crop thanks to the higher prices they demand for their crop. On the other hand, they will need to be able to sell their crop and, if they continue losing their market share or the demand for their product decreases, more of them will go out of business. At the other end of the scale, the large farm enterprises that have the best control on disease, the lowest labour costs and best yields, will continue making a profit and increase in size. This will result in a smaller sector with larger farms concentrated in regions allowing intensive horticultural practices.

7.4. OUTCOMES FOR STAKEHOLDERS

A number of outcomes have emerged from this study that highlight issues limiting the UK strawberry sector's ability to adapt and individual growers' adaptive capacity. One of these is the impending threat of a reduction in available plant protection products. The absence of crop specific and adequate products would severely limit the sector's ability to maintain the current trend in growth and yields. In view of the current lack of new options and safe chemicals, chemical companies need to invest more in the development of new and safe plant protection products for the soft fruit industry that would meet the minimum requirements under EC Regulation No 1107/2009, concerning the placing of plant protection products on the market.

The same applies to the plant nurseries running breeding programmes for strawberries. The lack of emphasis on developing disease-resistant varieties has left the sector with limited options in counteracting the decrease in availability of plant protection products. Although many growers suggested the use of resistant varieties to combat an increase in disease incidence with climate change, plant suppliers suggest that no such panacea exists as yet and that it would take around 10 years for one to become available. In light of this, the strawberry industry needs to spearhead breeding programmes aimed at increasing resistance against the major diseases affecting UK strawberry production, in order to limit the sector's dependency on plant protection products. For this to be successful, the breeding programmes need to have the support and backing of the major supermarket chains. Unless supermarkets promote the sale of disease-resistant cultivars, and not just the ones they believe to be attractive to customers, the breeding programmes will not have the required impact.

Another outcome of this study is the strategic advantage of early adaptation. In light of the potential impacts of climate change facing the strawberry sector, growers are advised to actively engage in adapting to, for example, a reduction in water availability or an increase in seasonal precipitation and flooding. By doing so, growers will have a competitive advantage in sustaining production and yields at optimal levels.

Regional policymakers and county councils should also allow the strawberry sector and wider horticultural industry to adapt to changes occurring in the last decade. Antagonism towards the use of polytunnels in certain regions in the UK risks alienating the industry into shifting its production to other regions, taking with it jobs and the accompanying cash flow into local communities. Local authorities should encourage responsible planning policy, while still ensuring economic growth in the sector. Campaigns against the use of polytunnels could risk harming the UK horticultural sector, placing further financial burdens on an industry that already operates on very tight profit margins.

The dependence on casual labour is probably one of the biggest and most difficult problems facing the UK strawberry sector today. The lack of an efficient mechanical facility to harvest strawberries means that growers have no other option but to employ large quantities of casual labour to collect strawberries during the extended season. Despite the development of mechanical harvesting systems in the past, these are still not as efficient as humans in picking strawberries, and a certain percentage of the fruit is damaged by the machine (Hayashi *et al.*, 2010, Yamamoto *et al.*, 2011). In spite of this, the intensification of strawberry production in the last two decades in the UK, has increased the need to develop alternative means to collect strawberries and keep harvesting costs down. The relatively high minimum agricultural wages mean that the British strawberry is as yet too expensive to export and/or compete with strawberries grown elsewhere in Europe. Having a mechanical harvesting system would enable the strawberry sector to lower running costs, ensure their profitability and increase their export potential, ensuring a market for further growth.

Another outcome of this study is the risk of introducing alien pathogens with imported plant material. The introduction of *Colletotrichum acutatum* in the 1980s and 1990s has shown the extent of responsibility of foreign nurseries in the movement of infested plant material across borders. In view of this, the UK strawberry industry needs to take steps to protect itself from such introductions by pressing plant nurseries to maintain the highest Phytosanitary standards. The strawberry sector has grown since the 1990s and has become very influential and a leader in Europe. This puts them in an ideal position to raise the importance of Phytosanitary control in plant nurseries, to minimise future risk of the movement of pathogens with plant material.

7.5. DIRECTIONS FOR FUTURE RESEARCH

The data generated through this study have contributed to a better understanding of a number of topics including agricultural restructuring in the UK strawberry sector, climate impacts on plant disease, and adaptation in the UK's highest grossing horticultural crop. Lessons learnt through this study could be useful to other agricultural sectors, particularly to other parts of the horticultural industry. Methods used throughout this study could also be used for other sectors. The disease datasets for strawberries obtained from FERA were just one of a series of records of a number of agricultural crops grown in the UK. The data for strawberries were actually less detailed than those obtained for other major crops. Use of these datasets could generate a wealth of information on the influence of plant disease on the restructuring of various agricultural sectors.

This study has also highlighted a number of other gaps that need further investigation. One of these is the potential impact of the use of migrant labour in the strawberry sector on rural communities. Does the wealth generated on strawberry farms flow into the rest of the rural community through this labour force and what impact does this have? Do different nationalities of workers affect the way income generated on farms flows into rural communities? By studying this further, the benefits and impacts of having an intensive strawberry sector employing thousands of workers in a rural environment could be assessed. This would help build arguments for or against the use of intensive horticultural practices and the need of migrant labour in rural landscapes. The outcomes could potentially influence policy makers in those regions where there is a clash between the strawberry industry and local authorities on the use of intensive cultivation methods.

The three disease models built in chapter 5 used data from published sources of literature to come up with a selection of conditions that would act as predictors of potential disease incidence. The sensitivity of the data to small changes in the chosen conditions, however, was not tested due to time constraints, prompting the need for further work through a sensitivity analysis on the chosen climatic conditions. The sensitivity analysis could help increase the level of confidence in the model by helping the reviewer indentify the parameters that are the key drivers to the results being achieved by the model (Taylor, 2009). This could give further strength to the outcome and be used to influence policy for adaptation within the strawberry industry to a change in disease incidence.

The impact of climate change on the potential geographic distribution of strawberry cultivation was only superficially covered in this study through assumptions made about the strawberry sector. This could also be studied further by using a software package such as the Climex Model. This would enable the generation of knowledge on where strawberries may be grown in the UK in the future. The disease models could then be run once again, using UKCP09 climate projections downloaded for those areas where the crop will be grown. This would give a more accurate assessment of the potential impacts of climate change on the strawberry sector's ability to cultivate the crop. The outcome could also potentially influence adaptation measures that could be taken up by the sector and by policy makers.

As a final point, the lessons learnt through this study could achieve greater impact were they to be disseminated to the interested stakeholders and end users. Whilst some of this material could contribute to a number of scientific publications, articles aimed at the horticultural industry and the end users will be prepared following the publication of this study. The data could also be of interest to an international audience, since some key businesses within the supply chain are influential internationally, and are having an impact on restructuring of other strawberry sectors throughout the world, including in Germany, Poland, South Africa and Australia.

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Chapter 9 Appendix

9.1. POSTAL QUESTIONNAIRE

Climate change and strawberry disease survey

Section A – General information

1 **Contact details.**

Your name					
Your nursery					
Address					
Post code					
Telephone		**Mobile**		**Fax**	
E-mail					

Section B – Production methods

2 **What percentage of your crop is grown in:** (for each say what percentage of that production systems is grown in soil and in growing medium)

	of total	with soil	with growing medium
Glasshouses	%	%	%
Tunnels	%	%	%
Floating mulches on non-tunnelled crops	%	%	%
Open field	%	%	%
Other	%	%	%
Example:Glasshouses	*30%*	*10%*	*90%*

3 What percentage of the crop you grew TEN YEARS AGO was in:

	of total	with soil	with growing medium
Glasshouses	%	%	%
Tunnels	%	%	%
Floating mulches	%	%	%
Open field	%	%	%
Other	%	%	%

4 During which month do you harvest your strawberries?

☐	January	☐	February	☐	March	☐	April
☐	May	☐	June	☐	July	☐	August
☐	September	☐	October	☐	November	☐	December

5 Which are the three most common strawberry varieties that you use, in terms of percentage area of your crop?

	Variety	Percentage
a.		%
b.		%
c.		%

6 Which of the following do you use? ☐ Everbearers ☐ June bearers

7 How long do you crop your strawberry plants?

☐ 1 year ☐ 2 years ☐ 3 years ☐ More than 3 years

8 Who supplies your planting material?

....

9 What percentage of your planting material is produced:

in the UK? [%] Overseas? [%]

Section C – Threats and opportunities to the strawberry sector

10 **Please list up to 4 issues that you consider to be important threats to UK strawberry production.** Please start with the most important threat first and list the rest in decreasing order of importance.

a.
b.
c.
d.

11 **Please list up to 4 issues that you consider to be important opportunities for UK strawberry production.** Please start with the most important opportunity first and list the rest in decreasing order of importance.

a.
b.
c.
d.

12 **Do you think climate change will have any impact on your strawberry business?**

[ ] **Yes** [ ] **No**

If your answer to this questions is no proceed to Section D

13 **What important threats might climate change bring to UK strawberry production?** Please start with the most important threat first and provide some brief reasoning for your answers. Please also include a timescale for the threat in the reasoning (eg. now, next 10 years etc.)

a.
Reasoning
b.
Reasoning
c.
Reasoning

14 **What opportunities might climate change bring to UK strawberry production? Please start with the most important opportunity first and provide some brief reasoning for your answers. Please also include a timescale for the opportunity in the reasoning (eg. now, next 10 years etc.)**

a.
Reasoning
b.
Reasoning
c.
Reasoning

15 **Do you think the threats or opportunities brought about by climate change will be felt in the same way throughout the UK? Explain why?**

16 **What effect will climate change have on strawberry diseases?**

There will be more disease incidence	☐
There will be less disease incidence	☐
Some diseases will increase while others decrease	☐
There will be more new diseases	☐
None	☐
I don't know	☐

17 **And why?**

Section D – Strawberry disease

18 What are the three most common strawberry diseases in your business?

a.

b.

c.

19 Rank the 3 most important factors that make strawberry cultivation susceptible to disease. (rank 1 being the most important)

	Use of wrong variety		**Growing in open field**
	Pesticide availability		**Weather conditions**
	Type of substrate used		**Use of non-certified material**
	Use of protection		**Other……………………………..**

20 What loss in production is caused by each of these diseases? (rank the impact from 0 being none, to 5 being severe)

	In a good year	**In a bad year**
Red core *(Phytophthora fragariae)*		
Black spot *(Colletotrichum acutatum)*		
Grey mould *(Botrytis cinerea)*		
Powdery mildew *(Podosphaera macularis)*		
Crown rot *(Phytophthora cactorum)*		
Verticillium wilt		
Mucor/Rhizopus		
Viruses		
Other (please specify)		

21 If these, which causes the greatest economic impact on your business and why?

22 What in your opinion are the three most effective ways of controlling or minimising strawberry disease?

a.

b.

c.

23 Do you use pesticides? ☐ **Yes** ☐ **No**

24 If yes, how do your BASIS qualified agronomists base their decisions on pesticide use? (Tick more than one if appropriate)

To spray on a precautionary basis to avoid disease outbreak ☐

When disease symptoms are detected ☐

Other (please state) ☐

25 If not, why not?

26 How much do you spend on strawberry-related pesticides annually? £ ……

Section E – Your future in strawberry production

Sections E and F are designed to help us gain a perspective on the relative proportion of the total sector that responds to this questionnaire and will help us interpret information provided in earlier sections of this questionnaire.

27 How do you see your strawberry business developing over the next five years?

28 Over the next five years, do you anticipate that:

You will change the area that you use for strawberry production?

☐ **Increase** ☐ **Reduce** ☐ **No change**

You will change the number of marketing channels that you operate?

☐ **Increase** ☐ **Reduce** ☐ **No change**

29 Where do you see the main focus of your market in the next 5 years?

☐ **More local** ☐ **More regional** ☐ **More national** ☐ **More outside UK**

☐ **Less local** ☐ **Less regional** ☐ **Less national** ☐ **Less outside UK**

☐ **No change**

Section F – Your general farm business

30 What is your status on the farm?

☐ **Owner** ☐ **Manager** ☐ **Tenant**

☐ **Other** (please specify) …………………………….

Land and agricultural enterprises

31 What is the total area of land that you manage? ………… Acres or Hectares

How much of this land is rented? ……………….%

32 What area of your land is used for strawberries? ………… Acres or Hectares

33 How has this area changed over the last ten years?

☐ Increased ☐ Decreased ☐ Remained the same

If it changed, why?

34 How long have you grown strawberries? ……………………………………………

35 What else do you grow or produce? ……………………………………………………

Section G – Sales and marketing

36 What was the weight of strawberries that you marketed last year?

……………………………………………………………………………………………………….

37 Is your total output supplied to supermarkets? ☐ Yes ☐ No

If yes, proceed to question 42

38 In terms of value of all sales, what percentage of your strawberries do you sell through the following marketing channels? Please make sure that your percentages add up to 100%

Box scheme	%
Farmers' market	%
Internet sales	%
Own farm shop	%
Independent retailer	%
Supermarket	%
Restaurants and private caterer	%
Processor	%
Producer/marketing co-operative	%
Wholesale market	%
PYO	%
Other (please specify)	%

39 How long have you been operating this way of marketing your produce?

…………………… years

40 What is the main focus of your strawberry sales (tick one only)

☐ Local ☐ Regional ☐ National ☐ Outside UK

41 How does this compare to five years ago?

☐ More local ☐ More regional ☐ More national ☐ More outside UK

☐ Less local ☐ Less regional ☐ Less national ☐ Less outside UK

☐ No change

42 Approximately what percentage of your strawberry production costs are related to the following?

Pesticide usage	%
Energy	%
Water	%
Consultant's costs	%
Buying plants	%
Fertilizer	%
Labour involved in fruit picking	%
Marketing and selling fruit	%
Capital investment in machinery	%
Capital investment in infrastructure	%
Other (please specify)	%

Thank you for you co-operation in completing this survey. For more information please go to the following link: http://www2.warwick.ac.uk/fac/sci/whri/research/climatechange/impact/strawberry/

If you know of other strawberry growers that would be interested in completing this survey, please forward them a copy.

If you have any queries about this questionnaire, please contact: e.calleja@warwick.ac.uk

9.2. INTERVIEW SCHEDULE

DATE OF INTERVIEW:

NAME:

ADDRESS OF FARM BUSINESS:

[*INTRODUCTION TO FIRST TOPIC :* "FIRSTLY, I'D LIKE TO ASK YOU SOME GENERAL QUESTIONS ABOUT THE FARM BUSINESS"]

SECTION A: The farm business

1. What is your status/role on the farm?

   ☐ Farmer/owner ☐ Manager ☐ Tenant ☐ Other (*please specify*)

2. What age bracket? Are there any other members of the family interested in taking over?

3. How big is your farm?

4. How many people work on the farm? Please outline family labour, full-time and part-time labour.

5. How many of these live locally? Regionally? In the UK? [explain the aim of your question]

6. From responses to an earlier survey we saw that labour was one of the major costs to the strawberry sector, accounting to 35% of the costs of production. How much of a limiting factor are labour costs to the industry and what in your opinion could be done to lower them?

Theme - Farm business and drivers affecting the sector

7. How important are strawberries to your business? What proportion of your business comes from strawberry production?

8. Which do you see as the most profitable commercial enterprise for strawberry production? What do you think are its greatest limiting factors?

9. Which best describes your system?
   ☐ PYO ☐ Medium sized farm ☐ use of polytunnels
   ☐ organic ☐ use of glasshouses ☐ open field
   ☐ Large farm with at least 10 office staff
   a. Why did you choose that particular system?

   b. Are you planning to continue using that system in the future and why?

   c. What do you think is the future of this type of growing system, in your region/in the UK?

10. What kind of commercial relationship do you have with your retailers? How does it work?

11. Who dictates the prices?
    a. Do they fix the prices in advance?

12. Do you have contractual obligations with your retailer?

13. What are the inputs and outputs that feed into your farm? (Appendix I) Where do you source your inputs? Local/Regional/National/From abroad

    [Prompts in case they do not mention them]

    a. Plants
    b. Pesticides
    c. Fertilisers
    d. Machinery
    e. Equipment
    f. Fixed infrastructure such as polytunnels/greenhouses
    g. Substrate/growing medium

Theme – strawberries in the area

14. Are there lots of strawberries grown in that area? Is it an important sector there?

15. Challenges?

16. Why here?

17. Are there any events organised here around the strawberry sector like fairs etc.

SECTION B: Plant disease in strawberries and disease management

Theme - Importance of plant disease

18. How often are you affected by plant diseases?
    Continuously/Regularly/Occasionally/Rarely

19. What disease(s) are they?

20. How did you detect and identify them?

21. Could you explain some of the costs that you incurred due to this disease loss and how you measured the losses? [Prompts – e.g. increasing amount spent on inputs? Decreased yield?] (e.g. 30% of yield?)

22. How did it affect the supply chain beyond your business? E.g. the businesses who you bought your inputs from and the businesses that you supplied? (Use diagram in *Appendix 1*)

23. In the past, how has plant disease ranked in your list of risks on the farm?

a. If it has been low in your priorities - why?

Theme – Disease Management?

TRANSITION: IF WE CAN MOVE ON TO TALK SPECIFICALLY ABOUT YOUR PLANT DISEASE MANAGEMENT

24. Do you have a plant disease management plan? What does it consist of?

25. How important are fungicides to your plant disease management plan?

26. Do you set your targets for spray timings at the beginning of the year? (do you buy in a certain amount of chemicals in bulk?).
    [Prompt - Units of fungicide applied….]

What does the future hold in terms of disease management?

27. How do you think that your management of plant disease will change in the future?

    a. Would a reduction in the range of available pesticides be a cause of concern? Influence of 91/414 *[only after they have offered initial answers]*
    b. Would the strawberry sector be able to survive a reduction of pesticide availability in view of this change in disease behaviour?

[TRANSITION: NOW I'D LIKE TO ASK A FEW QUESTIONS ABOUT CLIMATE CHANGE.]

SECTION C: Climate Change

28. Do you think climate change will affect your business?
    a. How?

    b. What threats do you think it might bring?

    c. What adaptations measures would you take to minimise the impact on your business?

29. According to the survey, Botrytis and Powdery mildew were the two most common diseases on strawberry farms, and the ones causing the greatest losses. According to our climate change forecasts, Botrytis is expected to __________ by ______% in this region, while mildew will _________ by ______%.
    a. Is this a cause of concern for the industry in this region?

    b. Would this affect your business and how?

    c. How might you react to this change?

30. Across the rest of the country Botrytis is expected to ____________ whilst powdery mildew will _________________.
    a. Is this a cause of concern for the rest of the UK strawberry industry?

    b. Do you think these regional differences might give a competitive advantage to certain regions?

31. Whilst these two diseases were found to behave so, Strawberry black spot was found to increase by ____% in your region.
    a. Is this disease of concern to you at the moment?

    b. Do you think it might become of concern?

    c. What would you do to adapt to this change?

32. For two of these diseases (Mildew and Black Spot), growing strawberries under protection might exacerbate the impact of climate change on disease growth.
    a. Would this discourage you in opting for protection in the future?

33. According to growers' opinions in the survey carried out last summer, climate change will bring about a number of threats, which includes the following list below. Do these threats brought about by climate change worry you and why? If yes how would you adapt your business to these challenges?
    a. Weather becoming too hot (difficult for workers)

    b. There will be more extreme events

    c. There will be warmer winters

    d. There will be earlier springs

    e. There will be poorer growing seasons

f. There will be earlier production (clash with Spain)

g. There will be a lack of sufficient water for irrigation

h. There will be more use of protection

i. Climate change will bring about a loss of the industry's infrastructure by a reduction in overall area

j. There will be changes in varieties

k. New pests will be introduced

l. Demand for strawberries might change

34. From overall responses to the survey we saw that most growers see cheap imports as a major threat to strawberry growers today. Do you think that this might still be the case with climate change in 20 years time, and why?

35. Are there any other threats that are of concern to you, and why?

36. What about opportunities?
    a. Would climate change bring new opportunities to the UK strawberry industry?

b. As a whole, do you see climate change as bringing more threats or opportunities to the UK strawberry industry? And why?

c. What would you do to take advantage of some of these opportunities?

[CLOSING: "_I APPRECIATE THE TIME YOU HAVE TAKEN OUT OF YOUR BUSY SCHEDULE TO TAKE PART IN THIS INTERVIEW. ARE THERE ANY OTHER COMMENTS THAT YOU WOULD LIKE TO MAKE ABOUT ANY OF THE SUBJECTS DISCUSSED?".]

WOULD IT BE POSSIBLE TO TAKE A NOTE OF YOUR EMAIL ADDRESS AND CONTACT TELEPHONE NUMBER?

PROMPT FOR FARM WALK…

Appendix 1:

SECTION A: **SECTION B:**

PRIMARY INPUTS:	**EFFECT ON INPUTS DURING DISEASE OUTBREAK:**
Plants Pesticides Fertilizers Machinery & Equipment Packaging Labels Polytunnels Growing media Workers’ Lodging Workers’ shopping	

FARM BUSINESS

OUTPUTS:	**EFFECT ON OUTPUTS DURING DISEASE OUTBREAK:**
First class fruit Second class fruit Frozen Fruit Jams	